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THE INFLUENCE OF TEMPERATURE AND CONCENTRATION
ON THE TOXICITY OF SALTS TO FISH

BY

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A. B. Trinity University, 1906.

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY
SUPERVISION BY Edwin Booth Powers.

ENTITLED THE INFLUENCE OF TEMPERATURE AND CONCENTRATION
ON THE TOXICITY OF SALTS TO FISH.

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY IN ZOOLOGY.

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INTRODUCTION

In previous work on the toxicities of ceratin substances to goldfish, the writer found that their physiological activities with few exceptions follow a general law. The following investigation was undertaken to determine the effect of temperature upon this general law and to correlate this effect with the physiology of the organism. Methods for the study of the deleterious effect of environmental factors are also suggested.

This work was carried on in the Zoological Laboratory of the University of Illinois under the direction of Professor Victor E. Shelford whom the writer wishes to thank for his many courtesies and helpful suggestions throughout the course of the investigation.

METHODS AND MATERIAL

All experiments were carried on at a temperature varying not more than a maximum of 0.2 to 0.3 of a degree centigrade. This almost uniform temperature was made possible by the use of a Johnson thermostat. The constant temperature apparatus consisted of an Alberene stone aquarium 183 cm. by 44.5 cm. by 34.5 cm. deep outside measurements, in which the water was 15 cm. deep into which vessels containing the solutions and fish were set. The temperature of the bath was regulated by the Johnson hot water thermostat placed at the center. It controlled the flows of hot and cold water which entered the tank at the end opposite the outlet. The temperature of the bath was

recorded by a Tyco recording thermometer (See Figure 1.); it was kept uniform throughout by agitating the water with small widely dispersed bubbles of air. When the flow of water was large (2 liters per min.) there was a variation of from 0.8 to 0.9 of a degree centigrade with three or more oscillations per ten minutes. With a very small inflow of water these oscillations were fewer and less in range and disappeared almost entirely and the temperature at the center of the tank became practically uniform (See Figure 1 A to B and C to D and for uniform temperature see E to F.). The difference in the temperature of the water at the two ends of the tank was very slight as was shown by readings taken from time to time.

The fish used in the experiments were kept in running water at a temperature of from 18 to 20 C. The goldfish were bought of a local dealer and the wild fish were obtained from small streams near by. The mortality of the wild fish was very slight following the second day after they were brought into the laboratory. These fish were not used in the experiments until after the mortality of the stock had ceased and were not used after having been kept in the laboratory two or three weeks. In the experiments the fish were tested in 1500 cc. of a solution contained in a two quart Mason jar which was kept closed with a rubber stopper. The experimental jars were kept in the constant temperature tank and the survival time of each fish recorded.

Distilled water was used in all experiments. This was prepared by condensing steam from a hot water tank of reboiled water. The condenser tube was made of Jena glass tubing. The water as collected from the condenser was strongly acid due to

the presence of an excess of carbon dioxide. After aerating with carbon dioxide free air for twenty four hours the water was found by analysis to contain:-

Physical examination.

Turbidity - - - - - 0

Color - - - - - 5

Odor - - - - - 2V

Residue on evaporation.-

Total solids - - - 32 to 42 parts per million.

Alkalinity as calcium carbonate.

Methyl orange - - 0 to 0 parts per million.

Chlorides.

As sodium chloride- 0 to 0 parts per million.

Ammonia nitrogen - - - - - 4 to 7 parts per million.

Albuminoid ammonia - - -0.06 to 0.102 parts per million.

This water was not rapidly fatal to fish. Two goldfish (Carassius carassius L.) lived ninety-five and ninety-nine days and six blunt-nosed minnows (Pimephales notatus Raf.) lived eleven, twelve, thirteen, fifteen, thirty, and thirty-two days respectfully in the distilled water. Two other blunt-nosed minnows jumped out of the water, one after seventeen days and the other after thirty-three days. The water was changed every seven days. This special water was used since it had been found that goldfish would live only from three hundred and fifty-two to five hundred and ninety-seven minutes in ordinary distilled water (Powers 1918).

EXPERIMENTAL DATA

It has been shown in previous work with goldfish that, when an individual is killed in a toxic substance, including acids, salts, alcohols, pyridine, caffeine, and phenol, the survival time of the goldfish is not directly proportional to the concentration of the substance used, but there is a uniform deviation from this relation which is common to all substances thus far tested with the exception of the chlorides of some of the heavier metals. Experiments were run with goldfish with lithium chloride and the blunt-nosed minnow and the straw-colored minnow (Notropis blennius Gir.) with the chlorides of ammonium, sodium, magnesium, calcium, and barium to determine the effect of temperature upon the toxicities of these salts. From these experiments it was hoped to determine the effect of temperature upon the deleterious results of any toxic substance which might appear in the habitat of the fish either as a natural environmental factor or as a contamination.

Experiments were run with the goldfish to determine the relative toxic activities of lithium chloride at 4°, 11.8°, 15.3°, 20°, 24.9°, 29.8°, and 34.8° C. The results of these experiments are given in Table I. In all tables the velocity of fatality which represents the rapidity with which the fish were killed is the reciprocal of the survival time. One hundred over the survival time is used instead of one over the survival time to avoid the use of fractions. The relative conductance was determined with a Washburn conductivity cell modified especially for this work and a Wheatstone bridge. A telephone receiver

with a fundamental vibration of 1000 per second was used instead of a galvanometer. The alternating current was generated by a small Leeds and Northrup high frequency generator driven by two storage batteries and regulated to produce 1000 alternations per second. Table II gives the ratio of increase in toxicity of the lithium chloride at concentrations from 0.046 N. to 0.488 N. for an increase of approximately ten degrees centigrade as measured by the actual survival time of the fish in any one concentration at the two temperatures. Tables III to VI give the survival time and the velocity of fatality of the blunt-nosed minnow in different concentrations of sodium chloride, magnesium chloride, calcium chloride, and barium chloride at 12.8°, 17.8°, 22.8°, 27.8°, and 32.8° C. The relative conductance is given in column five of the tables for each of the salts at the different temperatures. Table VII gives the ratio of increase in toxicity of the different concentrations of each of the four salts tested for an approximate rise of ten degrees centigrade. Table VIII is a summary of the relative conductance of sodium chloride, magnesium chloride, calcium chloride, and barium chloride for comparison. Tables IX and XIII give the survival time and the velocity of fatality of the blunt-nosed minnow and the straw-colored minnow in different concentrations of ammonium chloride. Tables XVIII and XIX show the antagonism of calcium chloride to sodium chloride and vice versa. All figures are graphic representations of data given the tables. In all cases the circles (•) and the plus signs (+) represent actual experimental data or calculations made from actual ex-

perimental data.

TOXICITY AND THE MEASUREMENT OF TOXICITY

Toxicity has been variously defined by different workers. A common definition is that any agent which, when introduced into the animal organism, is capable of producing a morbid, noxious, or deadly effect upon it, is said to be toxic. For the purpose of this paper toxicity will be taken to mean the effect of any agent which occurs in the habitat of the fish either as a natural environmental factor or as a pollution, the presence of which causes the death of the fish or interferes adversely in any way with its reproduction, development, or growth. Up to the present but very little work has been done in determining in a quantitative way the toxicity of naturally occurring and pollution substances. Shelford (1917) has determined the toxicities of a number of the coal tars and the coal tar wastes to certain species of fish by using the one hour survival time as a criterion. Wells has made a quantitative study of a number of species of fish to carbon dioxide, lack of oxygen (1913), salts (1915a), and carbon monoxide (1918).

On a previous occasion experiments were performed to determine the efficiency of the goldfish as a test animal in physiological assay work (Powers 1918). In this work it was found that the toxic activity of a substance bears a very definite relation to its concentration. It was found that as the concentration of a substance was increased, beginning with a very dilute solution, a concentration was found that would just kill the fish. This concentration was designated as the threshold of toxicity concentration. As the concentration was increased

from this point the velocity of fatality, which is the reciprocal of the survival time, increased at first very slowly. This was followed by a more rapid increase and in turn, at higher concentrations, by a less rapid increase. There is evidence that at still higher concentrations there was again a more rapid increase in velocity of fatality. In other words the ratio of increase in toxicity with a given increase in concentration of a solution as measured by the survival time of the fish decreases as the concentration is increased. This decrease in the ratio of increase in toxicity for any given increase in the concentration of the substance tested is more than sufficient to allow for a constant ratio of increase in toxicity for a given per cent of increase in concentration of the toxic substance. Thus a sigmoid curve is formed when the velocity of fatality is plotted as ordinate and the concentration of the substance tested is plotted as abscissa. See curve, CABG, Figure 2. This curve is taken as a representative of the typical form of curve given by all substances tested both in this and subsequent work with the exceptions of cupric chloride, cadmium chloride, and ferric chloride. The deviation of the velocity of fatality curves of these three salts from the normal, was explained in a previous work (Powers 1918). From a study of the curve CABG, Figure 2, it is seen at very low concentrations (0.0055 N. to 0.027 N.) of the ammonium chloride, i.e., C to A of the curve, the velocity of fatality curve rises very slowly with increase in concentration of the ammonium chloride. This is seen more plainly by an inspection of Tables IX and XIII. Columns three of these tables show a fall of survival time and columns

four the increase in the velocity of fatality with increase in concentration of the ammonium chloride. The slant of the velocity of fatality curve CABG, Figure 2, shows the rapidity of the increase of the velocity of fatality with the increase in concentration of the ammonium chloride. At first the upward curvature of the velocity of fatality curve is very small as compared to the increment in concentration of the ammonium chloride. As the concentration increases there is a more rapid upward curvature which finally approaches a straight line. From this portion, i.e., the portion A to B, the upward curvature becomes less and the velocity of fatality curve becomes concave downward. When finally at very high concentrations there is again a second phase at which the upward curvature is increased. This last point is shown in the velocity of fatality curve of the straw-colored minnow killed in ammonium chloride at 19.8°C. (Fig. 3) and Table XIII, since experiments were run over a much wider range of concentrations than in the other series of experiments. The velocity of fatality curve, Figure 3, is a graphic representation of the data of Table XIV. From this figure it is seen that the velocity of fatality curve approximates a straight line at 0.015 N. to 0.03 N. This is followed by a concave downward curvature from 0.03 N. to about 0.05 N. which is finally followed by a concave upward curvature from about 0.05 N. to 0.6 N. This last point has not been proven for all substances tested but there is evidence that it holds good for all substances that follow this same general law as these two curves are comparable to the curves of all toxic substances tested with fish

with the exception of the chlorides of certain of the heavier metals and conforms very strikingly with the equation, $\frac{1}{t} =$

$$Y = \frac{MK_2 + K_1X}{\log_e \left(\frac{M}{M-z} + \frac{K_2Mz}{K_1(M-z)} \cdot \frac{1}{X} \right)}$$
, which was formulated from the theory of toxicity and when plotted gives a similar curve.

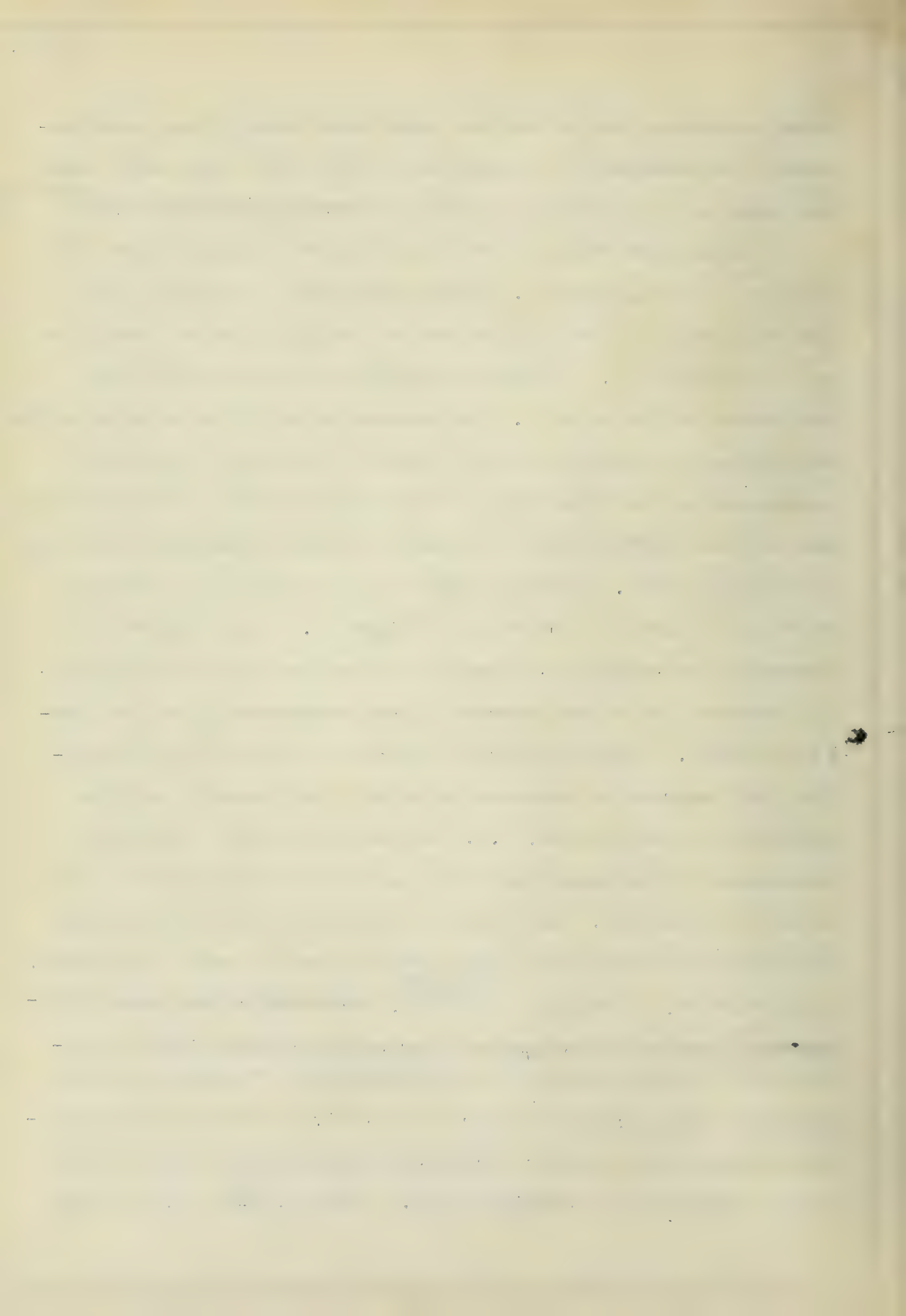
It is interesting on connection with this theory of toxicity that Hewitt (1907) and others have suggested that anaesthesia is due to the lowering of the oxygen consumption. The cause of this lowering of the oxygen consumption has been variously explained by different workers. Burge (1917) has shown that the catalase of the blood of the dog and cat is lowered as the oxygen consumption is lowered. Burge, Neill, and Ashman have also shown (1918) that the catalase is both destroyed in the blood and that its formation is inhibited by certain anaesthetics including chloroform, ether, and magnesium sulphate. The above equation was an attempt at an expression of the rate at which this combined action or similar combined actions of other protoplasmic poisons takes place. The expression is the result of the combination of two equations which represent the two actions which are taking place in the body of the animal. 1. the equation $\frac{dz}{dt} = K_1z(M-z)$ was taken to represent the speed at which the rate of metabolism is reduced by the inhibition of the formation of some essential metabolic product. M = rate of metabolism or the rate at which any essential metabolic product is formed. z = the amount of reduction of the rate of metabolism or the amount of the reduction of the rate of formation of any essential metabolic product. K_1 = a constant which represents the efficiency of the

reduced rate of metabolism in inhibiting metabolic processes or the efficiency of the reduced rate of the formation of any essential metabolic product in further slowing the rate of production of the essential metabolic product by slowing the rate of metabolic processes. Rahn (1916) has suggested that the enzymes of the cell are formed and destroyed probably at the same rate thus keeping the total amount of enzyme in the cell constant. This of course would be true only when the metabolic processes are uniform over a period of time. This is probably true of other essential metabolic products. Thus M would then represent the total amount of any essential metabolic product under normal and uniform conditions. For example with an animal killed with an anaesthetic such as chloroform, ether, or magnesium sulphate M would represent the total amount of catalase in the blood of an animal under normal conditions. z would represent the amount of catalase reduced by lowering the rate of production of catalase by the tissues of the animal which is brought about by the slowing down of the metabolic processes, i.e., it is autolytic.

2. The equation $\frac{dz}{dt} = K_1 X(M-z)$ was taken to represent the speed of inhibiting the rate of metabolism or the rate of the destruction of the essential metabolic product present in the body of the organism. X = the protoplasmic poison. K_1 = the efficiency of the protoplasmic poison in reducing the rate of metabolism or in destroying the essential metabolic product. With an animal anaesthetized with chloroform, ether, or magnesium the equation would represent the rate of destruction of the catalase already present in the blood of the animal. When these two equations

which represent the two actions which are taking place simultaneously are combined and integrated it gives the expression which was taken as representing the rate of fatality of protoplasmic ^{poisons}.

In all the velocity of fatality curves studied there is a portion (A to B, Figure 2.) which approaches a straight line, and in a criterion for the measure of toxicity can be considered as a straight line. AB when extended as a straight line cuts the X-axis at the point P. The concentration of ammonium chloride represented on the scale of the graph by the point P has been designated as the theoretical threshold of toxicity concentration. And the line PABF has been designated as the theoretical velocity of fatality curve. Thus the slope of the theoretical velocity of fatality curve or the angle θ (Figure 2.) can be taken to represent the rapidity with which the rate of velocity of fatality increases with the increase in the concentration of the toxic substance. The theoretical threshold of toxicity concentration and the rate of increase in velocity of fatality are the reciprocal of each other, i.e., as the theoretical toxicity concentration increases the toxic activity of the substance can be said to decrease. And when the rate of increase of velocity of fatality increases the toxic activity can be said to increase. An expression, T (toxicity) = $\sqrt{\frac{\tan \theta}{a}}$, which takes both these factors into consideration has been formulated (Powers 1918) to express the relative toxicities of substances. Perhaps a better and more simple expression for the relative toxicity is the equation of the theoretical velocity of fatality curve itself which is the equation of a straight line. That is, $\frac{y}{x-a} = K$. y = the



velocity of fatality. x = the concentration of the solution tested. a = the theoretical threshold of toxicity concentration. And K = a constant which can be taken to represent the relative toxicity of the substance. This equation which is more convenient than the above expression represents the same thing. The theoretical basis for the validity of the use of the equation will be discussed later.

The equation can be utilized to determine the relative toxicities of two substances or it can be used in the determination of the relative resistances of two different species of fish to injurious substances when corrections are made for differences of temperature at which experiments are run. It is the absence of some such criterion or basis for comparison which has lead to confusion in the results of the determinations of the relative resistance of fish. Wells (1918) has determined the seasonal variation in the resistance of the rock bass (Ambloplites rupestris Raf.) to lack of oxygen apparently without taking temperature into consideration.

THE EFFECT OF TEMPERATURE ON THE TOXICITY OF DELETED-IOUS SUBSTANCES TO FISH

a. The Effect of Temperature on the Toxicity of Lithium Chloride to Goldfish

A series of experiments were run to determine the effect of temperature toxic activity of lithium chloride to a one to two gram goldfish. The toxicity of the lithium chloride was tested at 4°, 11.8°, 15.3°, 20°, 24.9°, 29.8°, and 34.8° C. As is seen from Table I the toxicity of the lithium chloride increases



With a rise of temperature. From Table II it is seen that when the actual survival time of the goldfish or the velocity of fatality is taken as a criterion for toxic activity that the ratio of increase of toxicity for each approximate rise of ten degrees centigrade gradually increases from the lowest temperature to the highest temperature tested. This is what would be expected from the effect of temperature on biological reactions. The relation of the temperature quotient or van't Hoff's rule will be discussed later. Child (1913) has shown that Planaria with a higher rate of metabolism are less resistant than those with a lower rate of metabolism to toxic substances sufficiently strong to kill them before acclimation has had time to take place, i.e., the higher the rate of metabolism the greater the velocity of fatality. This is not only true in the case of Planaria but it has been found generally true of fish. The younger (smaller) fish of a species have been found in general to have less resistance to toxic substances than the older (larger) individuals (Wells 1913, Shelford 1917, and Powers 1918). The effect of the volume of the fish on its resistance to toxic substances is not known. This has never been satisfactorily worked out.

There is an increase in the velocity of fatality of the fish in toxic substances at higher temperatures due to the increased rate of metabolism at the higher temperatures. But in addition to this there should be an increase in the velocity of fatality of the fish due to the increased activity of the toxic substance itself at the higher temperatures. Snyder (1908, 1911) has collected and summarized data showing the effect of temper-

ature on the rate of increase of biological reactions such as the nerve conduction of the sciatic of the frog, respiration of larvae of the dragon-fly, coagulation, etc. Loeb and Ewald (1913) on the development of *Fundulus* embryos, Laurens (1914) on the development of *Amblystoma* embryos, Woodruff and Baitsell (1911) on the rate of reproduction of *Paramecium*, Krogh (1914, 1914a) on the rate of development of eggs and larvae of fish and frogs and the eggs and pupae of insects, Osterhout (1917) on biological reactions in general, Loeb and Northrop (1917) on the influence of temperature on the length of duration of the larval, pupal, and adult stages and the total duration of life of the fruit-fly, *Drosophila*, and other investigators have worked along the same lines. When the data of these workers are examined it is found that the relative effect of temperature decreases from the lower temperatures to the higher temperatures. In all vital phenomena a temperature will be reached where the rate of normal metabolic reactions will be retarded instead of increased and finally will be stopped altogether. As has been pointed out the ratio of increase of toxicity of the lithium chloride to the goldfish for a rise of ten degrees centigrade increases from the lower to the higher temperatures. This is the opposite to that of biological reactions in general. This however is what would be expected. That is, the velocity of fatality increases with rise in the initial rate of metabolism of the individual fish. And the relative effect of temperature in producing an increase in the rate of metabolism is lessened with a rise in temperature. And the effect of temperature on the chemical activity of a sub-

stance is more nearly constant, there being only a slight retardation in the effect of the temperature at the higher temperatures. Since the toxic value of a substance is dependent both on the rate of metabolism of the fish and the activity of the substance itself it would be expected that the effect of temperature on the toxicity of a deleterious substance would be the resultant of the effect on the rate of metabolism and the chemical activity of the substance itself. This is what has actually been found in the case of the effect of temperature on the velocity of fatality of goldfish when killed with lithium chloride. That is, the ratio of increase in velocity of fatality should always decrease less rapidly than the ratio of the relative effect of temperature on the rate of metabolism. And in some cases at least there should even be a rise in the ratio of the increase of the velocity of fatality. In no case would there ever be a decrease in the actual velocity of fatality at the higher temperatures as is actually the case with certain other biological reactions. This has been shown by Loeb and Northrop (1917) for the duration of life of the fruit-fly and by Groves (1917) for the duration of life for seed. The same was found true by Lillie (1917) for the activation of the starfish eggs with butyric acid.

b. The Effect of Temperature on the Toxicity of Sodium Chloride, Magnesium Chloride, Calcium Chloride, and Barium Chloride to Fish.

Experiments were run to determine the effect of temperature on the toxicity of certain of the environmental salts. The salts chosen for this purpose were sodium chloride, magnesium

chloride, calcium chloride, and barium chloride. Experiments were run with very low concentrations (0.025 N.) to very high concentrations (0.333 N.) of these salts with the blunt-nosed minnow with temperatures at 12.8°, 17.8°, 22.8°, 27.8°, and 32.8° C. Tables III to VI give the effect of rise of temperature on the resistance of the fish to these salts. Table VII shows the ratio of increase in toxicity with ten degrees increase in temperature of each of the four salts to the blunt-nosed minnow when the actual survival time or the velocity of fatality of the fish is taken as a criterion. When 0.227 N. calcium chloride with a ratio of 9.67 for 12.8° to 22.8° C., 0.025 N. magnesium chloride with a ratio of 9.56 and 0.05 N. magnesium chloride with a ratio of 17.75 for 17.8° to 27.8° C., and 0.1 N. magnesium chloride with a ratio of 93.6 for 12.8° to 22.8° C. all of which are much larger than the ratios of the same column, are dropped from the averages it is seen that the ratio of increase in toxicity of each salt increases from the lower to the higher temperatures.

c. The Effect of Temperature on the Toxicity of Ammonium Chloride to Fish.

Experiments were run to show the effect of temperature on the resistance of fish to ammonium chloride. The results of these experiments are shown in Tables IX to XIII. The velocity of fatality was increased with rise in temperature with the same relative ratio as was the velocity of fatality of the goldfish with lithium chloride. The results of these experiments will be further discussed in connection with the van't Hoff rule and determination of the relative threshold of toxicity concentrations

of deleterious substances.

d. The Relation of the Effect of Temperature on the Toxicity of Salts to Fish and van't Hoff's Rule.

Work that has been done on the influence of temperature on the reaction velocity of metabolic processes (Hill, Moore, Macleod, Pembrey, and Beddard 1908) has shown two distinct effects, one upon the central nervous system causing variations in the functional activity of the organs, these in turn influence the metabolic processes and the other on the tissues themselves influencing the rate of metabolic processes. In warm blooded animals low temperature stimulates the nerves which results in an increased metabolism and a rise in temperature results in a decrease in the rate of metabolism. In cold blooded animals the action of the nerves themselves like the other organs of the animal is under the influence of temperature. Thus the metabolic processes are almost invariably increased with a rise of temperature and decreased with a lowering of temperature. An exception to this rule has been found however in the case of the honey-bee clusters in winter (Phillips and Demuth 1914). It has been found with cold blooded animals that the ratio of increase in rate of metabolism for each rise of ten degrees centigrade as measured by oxygen consumption and carbon dioxide evolved and biological reactions in general approximates very closely two to three within certain temperature limits. This has been taken as proof that chemical dynamics hold within the animal organism. This view is held with greater confidence since it is known that the rule of van't Hoff is an empirical expression of the influence

of temperature upon chemical processes. There is generally a slight decrease in the Q_{10} of purely chemical processes with rise in temperature. Arrhenius' formula $\frac{V_1}{V_2} = e^{\frac{q}{R} \frac{T_1 - T_2}{T_1 T_2}}$ has been taken as expressing more nearly the truth where V_1 is the velocity of the process at the absolute temperature T_1 and q is the molecular heat of reaction. This formula has been very successfully applied to a number of reactions of a chemico-physical nature, i.e., haemolytic actions of alkalies, acids, bacterial poisons, and snake venoms, the weakening at high temperatures of a number of antibodies, and the combination of haemoglobin with oxygen (cited by Krogh 1914c). The van't Hoff rule has been applied to many physiological processes, i.e., those processes which take place only in the living organism or organs. Most workers have considered temperatures of very narrow range and have used these results in calculating the Q_{10} over a range of temperatures where this quotient does not hold. One has only to stop and think to see that the Q_{10} will vary from a point where it approaches infinity on the one hand to a point where it drops to zero on the other hand at least in those animals which are able to be frozen or go into hibernation at very low temperatures. The Q_{10} approaches just as near infinity when the hibernating animal passes out of the state of hibernation as the metabolic processes had approached zero during the hibernation of the animal. While on the other hand the Q_{10} is reduced to zero when a temperature is reached at which all metabolic processes cease. Most workers have arbitrarily chosen the range of temperature that shows the Q_{10} of the proper magnitude - between 2 and 3 - as

that which most reliance is to be placed. This generally approximates the mean of the temperature range for normal metabolic activity. Others seeing the variation of the Q_{10} have attempted to explain its cause. Snyder (1911) has said, "in fact, the writer knows of no case where this variation does not occur". Blackman (1905) says, "As regards the rate of metabolic chemical change in the organism at high temperatures, this law clearly does not express the whole truth. If it did we should expect, with increasing temperature, all vital processes to proceed with ever-increasing velocity till the fatal temperature was reached at which some essential proteid coagulated or some other connexion was dislocated, and the whole metabolic machinery came suddenly to a standstill". The falling off of the Q_{10} at higher temperatures is explained by Blackman as being due to a time factor and he points out the fact that Sachs has shown that the higher the temperature the more quickly the fatal effect ensues and that a short exposure at high temperatures will not kill while long exposures at lower temperatures will prove fatal. He concludes from Matthaei's (1904) experiments on carbon assimilation that: 1. At high temperatures (30° C. and above for cherry-laurels) the initial rate of assimilation cannot be maintained, but falls off regularly. 2. The higher the temperature the more rapid the rate of falling off. 3. The falling off at any given temperature is fastest at first and subsequently becomes less rapid. Blackman has calculated the theoretical initial value of assimilation from the rate of falling off of the assimilation at any given temperature. Thus by extrapolation he has formulat-

ed a curve at higher temperatures which conforms to a van't Hoff curve. Pütter (1914) in his experiments on the skin respiration of the frog has attempted to show that the deviation of his curve from that of a van't Hoff curve was due to the superposition of exponentials. Snyder (1908, 1911) explains the variation as being due to the low diffusion velocities, low temperature coefficient of viscosity, the low temperature coefficients of dielectric capacities, and the migration velocities of ions. Osterhout (1917) suggests that when substances are formed and are at once broken down, as is the case with many metabolic processes the reactions which form the substances may differ from that which destroys it. This he claims would cause a variation in the Q_{10} . The direction of the variation would thus depend upon which of the two reactions had the larger coefficients.

It is not the purpose of this paper to produce evidence that any given physiological activity is or is not a chemical process rather than physical, but rather to determine if there is any uniformity in biological reactions and if possible to determine in what way these processes are controlled by external factors. There seems to be a great uniformity in the trend of the Q_{10} wherever determinations have been made over any very great range of temperatures. In such diverse biological reactions as the gastric hunger movements of certain of the lower animals (Patterson 1917), the regeneration and the duration of life of the Tubularia crocea (Moore 1910), the radial growth rate on solid medium of the fungus Pythiacystes atrophthora (Fawcett 1917), and many other biological reactions (Snyder 1908, 1911), the van't Hoff coefficient - 2 to 3 - holds good for only a very

narrow range of temperatures. When the literature on the effect of enzyme action is examined the same thing is found to be true. Rahn (1916) who has collected data on this point discusses this material in the light of Tamman's theory and subjects it to an exhaustive mathematical examination. He shows that in all cases that the temperature coefficient is large at the lower temperatures and gradually decreases until at very high temperatures it drops to zero. Rahn suggests an explanation of this variation of the temperature coefficient in that he believes that at least in such as the alcoholic fermentation that destruction of the enzyme (zymase) occurs within the cell but at normal temperatures the enzyme is reproduced as rapidly as it is destroyed so that the amount of the enzyme remains the same. He also believes that at higher temperatures Tamman's principle comes into play. He postulates a thermolabile agent in the cell and applies the same principle to growth and reproduction.

Green (1870), Earll (1878), Dannevig (1894), Edwards (1902), Reibisch (1902), Williamson (1910), Sanderson and Peairs (1913), and Johansen and Krogh (1914) have done work leading up to the conception of thermal constant for biological reactions. Harvey (1911) showed that the rate of conduction of nerve impulse of the nerve-ring of the sub-umbrella of the medusa *Cassiopea* increased in a linear ratio as the temperature is raised. Mayer (1914) who repeated Harvey's experiments on *Cassiopea xanachans* affirmed Harvey's results, i.e., the increase in conduction of nerve impulses is arithmetically proportional to the increase in temperature. While finally Krogh (1914, 1914a) and Sanderson

and Peairs (1913) called attention to the close approximation of thermal constants of development to an equilateral hyperbola when temperature is plotted as abscissa and length of time required to pass any particular stage is plotted as ordinate. These workers hold that the effect of temperature on development does not follow van't Hoff's rule. Loeb and Northrop (1917) found the same high Q_{10} for *Drosophila* larval and pupal stages at low temperatures with a gradual decrease up to the temperature at which development would no longer take place. But with the duration of life of the imago stage their results were different. There was no tendency for the Q_{10} to decrease at the higher temperatures but instead it increased. This fact was used by Loeb and Northrop to strengthen their argument that it was the falling off of the Q_{10} in the larval and pupal stages that was responsible for the straight line limits of the velocity of development curve and states, "that the straight line character of the curve does not militate against the assumption that we are dealing in all these curves (curves for the rate of development of larvae and pupae and the duration of life of the imago and the total duration of life of the fruit-fly) with a temperature coefficient of the order of that of a chemical reaction". This seemingly unsimilarity of the two sets of curves will be discussed a little later.

A COMPARISON OF THE TEMPERATURE TOXICITY CURVE
TO THE TEMPERATURE METABOLISM AND THE TEMPERATURE
STANDARD METABOLISM CURVES OF OTHER WORKERS

Krogh (1914c) in his work on the effect of temperature on what he calls standard metabolism* has shown that Q_{10} is not a constant but gradually decreases from the lower temperatures to the higher temperatures. Leitch (1916) in attempting to show Blackman's method of extrapolation in calculating the effect of temperature on the growth rate of Pisum sativum untenable has compared his rate of growth curve to Krogh's standard metabolism curve and claims that the two are in agreement as well as a curve drawn from Kuijper's data on the effect of temperature on the respiration of Pisum. Leitch claims that the Q_{10} does not follow the van't Hoff rule. Others have attempted to show the applicability of the van't Hoff rule by approaching it from other points of view. As has already been mentioned Loeb and Northrop (1916) studied the effect of temperature on the duration of life of the fruit-fly. They determined both the duration of life of the imago stage and the entire dur-

*Krogh defines standard metabolism as the metabolism obtained when no assimilation of food is taking place, when movements are prevented, and muscular tone either abolished or brought down to a minimum. He states that when external conditions are unaltered that the metabolism is approximately constant at least over short periods of time.

ation of life. Lillie (1917) has studied the effect of temperature on the time required to activate starfish eggs by treatment with butyric acid. Groves (1917) determined the duration of the life of stored seed. These workers found no tendency for the Q_{10} to decrease at the higher temperatures. Thus there is no portion of their reciprocal curves which approach a straight line. This is additional proof that there is no portion of the reciprocal curves, i.e., the curves of the rate of development of any definite stage of the animal organism at different temperatures and of the velocity of fatality of fish in different concentrations of a toxic substance, which is actually a straight line but approaches a straight line where the curvature is changed from a concave upward direction to a concave downward direction due to the gradual decrease of the Q_{10} with rise of temperature (Powers 1918). The extent of the region in which the reciprocal curves approach a straight line is dependent on the rapidity with which the Q_{10} decreases in value with rise of temperature. When there is no decrease of the Q_{10} as the temperature is raised or the decrease is not sufficiently rapid (Krogh, Q_{10} for metabolism of Tenebrio molitor 1914b and the Q_{10} for standard metabolism 1914c) the reciprocal curve continues to be concave upward. (In the metabolism reciprocal curves there is probably a rapid decrease in the Q_{10} , i.e., the upper temperature limits of metabolism, which will cause the reciprocal curve to change to a concave downward direction. But at higher temperatures the metabolism becomes very irregular, Leitch 1916). When the survival time of the gold fish is taken as a criterion the effect of temperature

on the toxicity of the lithium chloride resembles that of the effect of temperature on standard metabolism of goldfish as found by Krogh (1914c). Krogh found that the relative effect of temperature on standard metabolism of a toad, a frog, a goldfish, and a puppy were approximately the same. Table II shows the Q_{10} for the toxicity of lithium chloride to goldfish when the actual survival time is taken as a criterion. This is not calculated but taken from actual experimental data of experiments which were run at approximately ten degree intervals. Table XIV shows the Q_{10} when K of the equation of the straight line of the theoretical velocity of fatality is taken as a measure of relative toxicity of the lithium chloride at different temperatures. The theoretical velocity of fatality curves of the goldfish when killed in lithium chloride solutions at 4° , 11.8° , 15.3° , 20° , 24.9° , 29.8° , and 34.8° C. are shown in Figures 4 to 10. These curves are drawn from data given in Table I. Figure 11 is the superimposition of the theoretical velocity of fatality curves for the temperatures tested. When the relative toxicities of the lithium chloride at the different temperatures, Figure 11, is plotted a curve shown in Figure 12 is given. Figure 13 shows Krogh's temperature standard metabolism curve of certain vertebrates including a goldfish. Figure 14 is a graphic representation of the Q_{10} when calculated on the basis of the temperature toxicity curve, Figure 12. See Table XIV. The more or less sharp upward trend of the Q_{10} curve at the higher temperatures, Figure 14, is due to an additional factor which has entered. That is, the higher temperatures is nearing the upper limits of temperature indurance of the goldfish. A few of the goldfish

died in tap water at 34.8 C. and all fish tested died when the temperature was raised to 36 to 37 C.

When the temperature toxicity curve of the lithium chloride to goldfish is compared to Krogh's temperature standard metabolism curve of vertebrates, Figure 13, it is found that the two do not coincide but that the temperature toxicity curve approximates the square root of the temperature standard metabolism curve. (See curves, Figures 12 and 13). Table XV gives the ratio of the square root of Krogh's temperature standard metabolism curve and the temperature toxicity curve. This ratio shows a slight rise of the temperature toxicity curve above that of a square root of standard metabolism temperature curve both at the higher and lower temperatures. Loeb and Northrop's (1917) data (Table XVI) for the reciprocal of the total duration of life and the duration of life of the imago of the fruit-fly conforms fairly well with Krogh's (1914b) temperature metabolism curve for the pupa of Tenebrio molitor when relative values of the reciprocals of the duration of life of the imago of the fruit-fly are compared to the metabolism of the pupae of the meal-worm at the same temperature. There is a slight variation at the higher temperatures. This is shown graphically in Figure 15. The curve was drawn from data taken from Krogh (1914b). The plus signs (+) represent the duration of life of the imago and the crosses (X) represent the total duration of life of the fruit-fly. Lillie's data, on the other hand, for the activation of starfish eggs with butyric acid conforms less exactly with Krogh's temperature metabolism curve. Table XVII, taken from Lillie (1917), gives the mean optimum time of exposure of star-

fish eggs to 0.006 N. butyric acid to activate them at different temperatures. Figure 16 shows the superimposition of the velocity activation (the reciprocal of the time required to activate the starfish eggs with the butyric acid at different temperatures) of the starfish eggs, as calculated from Lillie's data, on Krogh's temperature metabolism curve. The crosses (X) represent group A and the plus signs (+) represent group B. This graph shows that the velocity of activation is higher at the lower and higher temperatures than the relative rate of metabolism of the pupa of the meal-worm. Sollmann, Mendenhall, and Stingel (1915) found that the effect of temperature on the time required for systolic standstill of excised frog's heart injected with ouabain corresponded very nearly to the square of the heart rate quotient. These workers suggested as an explanation in the basis of Weizsaecker's observations that the activity of ouabain is proportional, independently, to two factors, viz., the heart rate and the temperature. That is, when the temperature and the activity of the heart both varied the activity of the ouabain would increase by the temperature factor multiplied by the rate factor. And they suppose that the temperature affects the rate of the heart and the ouabain response about equally, and thus the temperature would increase the activity by the square of the temperature quotient. The agreement of Loeb and Northrop's data to the temperature metabolism curve of Tenebrio molitor pupae is what one would expect provided that the relative effect of temperature on the metabolism of all invertebrates is the same. This last point has not been demonstrated. However, Krogh has

suggested its possibility. Many insects in the imago stage do not take food. Thus you would expect at least that the duration of life in the imago stage to be very closely associated with the rate of metabolism. This point is further emphasized by the fact that Krogh (1914a) found that the amount of carbon dioxide given off by the pupa of the meal-worm during the pupal stage is constant at all temperatures in which development was normal. Again the relation of time required to activate the starfish egg with butyric acid (Lillie 1917) at different temperatures and the temperature metabolism curve agrees with expectation. That is, according to hypothesis suggested by Lillie (1915, 1916) the activation process consists essentially in the production of a definite reaction product designated by Lillie as the activating substance. Lillie has shown that the rate at which the butyric acid takes part in the process of activation is directly proportional to its concentration and suggests that the interaction has the character of a monomolecular reaction. This being true the temperature should effect the activating and the metabolic processes alike. Thus the relative increase in the amount of activating substance would be proportional to the relative increase in the rate of metabolism. By an inspection of the graph, Figure 16, it is seen that the velocity of activation is higher than the rate of metabolism of the pupa of the meal-worm at both the low and high temperatures. This might be explained as Lillie has pointed out that temperatures below 8° C. and above 28° C. there is a marked activating effect on the eggs. This possibility will account for the higher rate of activation at these temperatures. The fact that the effect of temperature

on the toxicity of lithium chloride to the goldfish follows a curve which is the square root of the curve of the effect of temperature on standard metabolism of the goldfish might be explained on the ground that the lithium chloride attacks some intermediary substance of metabolism. Burge, Neill, and Ashman (1918) have shown that chloroform, ether, magnesium sulphate, and certain other substances attack the catalase of the blood of the cat, dog, and rabbit when given these substances. Thus in this case one is dealing with the effect of a substance the value of which is equal to the substance introduced. While in the case of the activating substance that is formed in the egg of the starfish is determined by the rate at which the butyric acid acts on the reacting substance in the cell. Thus the effect of the lithium chloride would have to be considered as a reacting substance and not as a product of a reaction. Thus from the law of dynamics when the two reacting substances are effected at the same rate the effect on the reaction product would be equivalent to the square of the effect on the reacting substances in a dimolecular reaction or the effect on the rate of activity of the reacting substances would be the square root of the effect on the rate of production of the reaction product.

Experiments were also run with the blunt-nosed minnow to determine effect of temperature on the toxic activity of ammonium chloride to this fish. The results of these experiments are shown in Tables IX, X, and XI. Figures 17, 18, and 19 are graphic representations of these experiments. When the relative toxicities of the ammonium chloride at 14.2° , 19.8° , and

24.9° C. are superimposed on the temperature toxicity curve of lithium chloride to the goldfish it is found that there is more or less agreement between these two sets of experiments. See Figure 20.

Although there is a more or less of an agreement of the Krogh temperature standard metabolism curve and the temperature toxicity curves of lithium chloride and ammonium chloride the explanation of the effect of temperature in increasing the activity of a protoplasmic poison is no doubt not so simple. Other factors such as muscular activity, muscular tension, digestion, and other physiological processes must be taken into consideration. This explanation has been suggested only as a working hypothesis.

A METHOD OF MEASURING RELATIVE RESISTANCES OF FISH TO DELETERIOUS SUBSTANCES AND THE COMPARATIVE RESISTANCE OF CERTAIN SPECIES OF FISH

In earlier work (Powers 1918), as has already been stated, the relative toxicities of substances of certain poisons to goldfish have been determined by the expression $T = \sqrt{\frac{\tan \theta}{a}}$. In this work it has been found more convenient to use the constant of the equation of the theoretical velocity of fatality curve in determining the relative toxic activity of a substance at different temperatures. This equation is the equation of a straight line since the theoretical velocity of fatality is a straight line. The validity of this method can be shown by a consideration of Figure 21. The curve CABG represents the velocity of fatality of the blunt-nosed minnow when killed in different con-

concentrations of ammonium chloride at 19.8° C. when one block abscissa represents 0.008 N. ammonium chloride and the curve C'A'B'G' represents the same data when one block equals 0.016 N. ammonium chloride. In both curves four blocks ordinate represents one unit of velocity of fatality. This is equivalent to having two substances one of which has just twice the toxic activity as the other and in which both follow the same law. Thus any point on the velocity of fatality curve C'A'B'G' is just one half the distance from the Y-axis as the point on the velocity of fatality curve CABG on the same parallel to the X-axis. Since this is true for any point on the velocity of fatality curve C'A'B'G' it is true for all points and is true for the portion A'B' and AB of the two curves. That is, the portions A'B' and AB of the curves bear the same relation to each other as the entire curves C'A'B'G' and CABG bear to each other. Thus what is true of the curves C'A'B'G' and CABG is also true of the curves P'A'B'F' and PABF. Thus the theoretical velocity of fatality curves can be taken as a representation of the true velocity of fatality curves. Since this is true the constant, K, of the equation of the theoretical velocity of fatality curve is taken as the most natural criterion for the relative toxicity of any substance or the relative toxicities of the same substance at different temperatures. The constant, K, of the equation of the straight line can also be taken to represent the actual threshold of toxicity concentration C' and C since they are parallel points on the two curves. It is also seen from the graphs that the true relative toxicities cannot be determined by comparing the relative time required to

kill the fish in the two substances but that relative toxicity can be determined more or less exactly by comparing the concentrations of the two substances which kill the fish during any fixed time. Figure 22 shows the same velocity of fatality curve CABG as shown in Figure 21 and a hypothetical velocity of fatality curve CA'B'G' in which the effect of the deleterious substance is increased by two due not to the toxic activity of the substance but due to the increased susceptibility of the fish to the toxic action of the substance as a result of the higher rate of metabolism of the fish. That is, at any one concentration of the deleterious substance the velocity of fatality of the fish with the higher rate of metabolism is twice as great as the one with the lower rate of metabolism. Thus, theoretically a fish of the same species would have the same threshold of toxicity concentration provided the difference of susceptibility was due only to the difference in the rate of metabolism. This theoretical curve does not hold in its entirety at least for Planaria as Child (1915 and citations) has shown that at high concentrations of certain toxic substances that the Planaria with the highest rate of metabolism die first while at very low concentrations of the toxic substance the order of time until death is reversed, those with the lowest rate of metabolism dying first. Other factors such as size of the individual and the rate of absorption of the deleterious substance probably plays a part. This hypothetical curve can be taken only as illustrating the tendency of the direction of the velocity of fatality curve, when the velocity of fatality is due to susceptibility of the fish and shows that the equation of the straight line can be taken only as a close ap-

proximation of relative toxic values and is more nearly the truth than any other criterion thus far suggested as a measure of relative toxic activities. This hypothetical curve also explains why all theoretical velocity of fatality curves of toxic substances do not intersect at some one point on the Y-axis. That is, there are two factors to be taken into consideration in the determination of relative toxicities. One is the difference in susceptibility of the fish to the toxic substances and the second is the difference in the toxic activities of the substances themselves. There are certain evidences that the velocity of fatality curves of lithium chloride to goldfish at different temperatures do not all meet at the same point, S, (Figures 4 to 10 and Figure 11) but this was taken as an approximation of the truth and as a method which can be utilized in obtaining a better understanding of the relation of fish to deleterious substances.

When the equation of the straight line is used as a criterion for the measurement of the susceptibility of a fish to ammonium chloride the resistance of the fish which is the reciprocal of the susceptibility is found to be as follows:-

<u>Notropis blennius</u> Gir.	(1.5 to 2.0 g.)	has a resistance of	1.0
<u>Pimephales notatus</u> Paf.	(Approximately 2 g.)	" " "	1.5
<u>Carassius carassius</u> L.	(3.0 to 4.9 g.)	" " "	3.0

These calculations are made for the size of the fish mentioned above only. The order of the species may not be the same at different stages of the life history of the fish.

A COMPARISON OF THE RELATIVE TOXICITIES OF CERTAIN
OF THE ENVIRONMENTAL SALTS AND THEIR ELECTRICAL CON-
DUCTANCE

Much work has been done to determine the exact cause of the toxicity of the elements or the mechanism of their actions. Some of the earlier views held were that the toxicity of the elements of isomeric groups were associated with the atomic weights of the elements (Blake 1883, 1887) or their toxicity was associated with their position in the periodic system (Botkin 1885). In recent years the toxicity of the elements have been attributed to the free electric charge or the atom itself while in the atomic state or that toxicity is due to the solubility of the substance. Mathews (1904) has suggested solution tension of the element as a function of its physiological activity. When experiments were run with the chlorides of sodium, magnesium, calcium, and barium to determine the effect of the temperature on the toxicity of these salts the electrical conductance of each of the salts was determined at each of the temperatures to ascertain the relation of the toxicity and the electrical conductance of the salts if there be any.

When the relative toxicities of sodium chloride, Calcium chloride, magnesium chloride, and barium chloride are approximated at 17.8° C. by using the theoretical velocity of fatality as a criterion for the measurement of relative toxicity it is found that they arrange themselves in the order named with the least toxic first and the most toxic last. This can only be an approximation since there were only a few experiments made in the

straight line limits of the velocity of fatality curve which seems to approximate 0.25 N. at least for the first three chlorides named. But when the velocities of fatalities of each of the concentrations at the different temperatures tested are averaged for each salt and the averages taken as a criterion for relative toxicity the arrangements of the salts in order of their relative toxicities is somewhat different. They arrange themselves as follows:- Magnesium chloride, calcium chloride, sodium chloride, and barium chloride with the least toxic first and the most toxic last. This is due to the high velocities of fatality of the fish in sodium chloride at 22.8° and 27.8° C. These two sets of experiments seem to be erratic as compared to other temperatures at which the sodium chloride was tested and also when the straight line criterion is applied to the data at these high temperatures. See Table III and compare to Tables IV, V, and VI. However neither of these orders given for the relative toxicities of the salts corresponds to the order of electric conductance of the solutions of the salts tested. Compare Tables III, IV, V, and VI with Table VIII.

ANTAGONISM AND ITS POSSIBLE UTILITY IN NATURAL POLLUTED WATERS

A few experiments were run with calcium chloride and sodium chloride to ascertain if there are any relations between the antagonism curve and the toxicity curves of these two salts. A 0.297 N. calcium chloride solution to which varying amounts of sodium chloride were added was tested. In these experiments,

Table XVIII, that the antagonism of the sodium did not at any concentration tested amount to more than the additive effect of the sodium chloride added. That is, from the pure calcium chloride solution there is more or less of a decrease in the survival time of the fish. But by comparing Table XVIII with experiments in which the fish were killed at 22.8° C., Table V, it will be seen that the actual antagonistic effect of the sodium chloride was increased up to the highest concentration of the sodium chloride used. That is, the falling off of the survival time of the fish was less rapid in the mixture of the calcium chloride and sodium chloride, per actual concentration of salts than an equivalent concentration of pure calcium chloride or sodium chloride, Table III. This actual antagonism continued to increase up to the highest concentration of the sodium chloride used, "

In the experiments with a 0.297 N. sodium chloride solution to which varying amounts of calcium chloride was added there was a greater antagonistic effect than the additive effect of the calcium chloride added. The antagonistic effect increased over that of the additive effect of the calcium chloride added until the calcium chloride added amounted to approximately 10% of the total salts in solution. From this point on the survival time of the fish fell continuously up to the highest concentrations of the calcium chloride used, Table XIX.

These experiments show that there is no relation between the antagonism and the toxicity curves. They also show that the antagonistic effect of calcium chloride and sodium chloride is most effective when the calcium chloride and the sodium chloride

are present in the ratio of normalities of about one to ten. These results agree fairly well with those of Osterhout (1914) who found the most effective ratio of equal toxic solutions of these two chlorides to be one of calcium chloride to twenty of sodium chloride. These experiments show in addition to the fact that a definite ratio must exist between two antagonizing salts to be most effective that if this ratio is not approximated the addition of an antagonistic salt to a toxic solution may be detrimental instead of beneficial. Thus in all treatments of natural waters which have become polluted the ratio for the most antagonistic effect of the substance added must be determined for the treatment to be most effective.

GENERAL DISCUSSION

The fact is well known that bodies of water become uninhabitable for some of the most valuable food fish both through natural causes and contamination. Work has been done that indicate that the conditions (Shelford 1911, 1911a) and the reactions of the water (Shelford 1911b and Wells 1915, 1915a) have more to do in determining the habitability of a body of water than other factors such as the availability of food. Shelford (1911a) has shown that fish do not always occur where its natural food is most abundant. It has been shown by reaction experiments (Shelford and Allee 1913 and Wells 1915, 1915a) that the fish generally avoid injurious substances which they naturally encounter in nature. But (Shelford 1917) the avoidance of injurious substances which do not generally occur under natural conditions is not so marked. In fact the fish may react positively to such

substances.

Liebig's law of minimum, as is generally stated, "the yield of any crop always depends on the nutritive constituent which is present in minimum amount" (Hooker 1917), can be applied to the habitability of a body of water for fish. But as Livingston (1917) has stated, "this principle is still quite incomplete logically and its statement will assurdly become more complex as our science advances". Hooker (1917) has called attention to the fact that Blackman has shown that the assimilation of carbon is very complex and depends on at least six factors; 1. Temperature, 2. Light intensity, 3. Carbon dioxide supply, 4. Water supply, 5. Chlorophyll, and 6. Enzymes. With fish the deleterious effect of a substance may depend on the stage of the life history of the fish, whether it be the developing egg, a young and rapidly growing fry, or an older or an adult fish. And while in any of the free moving stages of the life history of the fish the effect of the deleterious substance might be determined by the physiological state of the fish which will cause it to become more sensitive or less sensitive and thus react more energetically or less energetically to any environmental factor. While at all stages of the life history of the fish a deleterious substance may become injurious more rapidly under one set of conditions than under another set of conditions. Or a substance may not be injurious under one set of conditions while under other conditions it would be injurious. One of the environmental factors which determine the rapidity with which a substance becomes fatal is temperature. Temperature has been shown by the chemist and

physicist to increase the rate of chemical and physical phenomena up to the point where the substances are broken down or destroyed at the given temperature. The same is true of biological reactions with certain qualifications, i.e., at higher temperatures these reactions become irregular and in fact are retarded in rate.

The purpose of the experiments discussed in the preceding pages was to show the relation of the temperature factor on the effect of deleterious substances on the fish in natural bodies of water. The question is raised is the effect of deleterious substances on the fish due only to the physiological state of the fish or are there other factors to be taken into consideration. And if there is a change in the physiological state of the fish is this change of such a nature that it makes the fish more resistant when the deleterious substance is most active or does the resistance of the fish fall with the rise in the activity of the injurious substance or substances. Wells (1916) has drawn a curve from data of experiments to show the seasonal resistance of the rock bass (Ambloplites rupestris Raf.) to lack of oxygen. His curve shows that the rock bass is least resistant to lack of oxygen in August. Its resistance rises very slowly during September and October and reaches its maximum during April and May after which it falls rapidly to its lowest ebb at the last of July and in August. No temperature data is given. So it is not known just what part temperature played in these experiments.

Experiments already discussed show that there is a marked fall of resistance of a fish to a deleterious substance with rise in temperature. Thus the resistance of a fish as effected by

temperature is least during the summer months and rises during the fall reaching its highest point during the winter months and falling again during the spring. Not only would there be a seasonal rhythm but there would be a daily rhythm. Thus the habitability of bodies of water would depend on the length of the warm season. The longer the duration of the warm season the more fatal would be the effect. Or if there is a difference in the resistance of the different stages of the life history of the fish or the physiological state of the fish due to seasonal rhythm the habitability of the body of water would then depend on the temperature of the water at the period that the fish is least resistant, or the stage at which it is most sensitive and reacts most vigorously to invironmental or pullution factors.

In resent years the fish culturist has become interested in making bodies of water which have been made uninhabitable by pollution again favorable for fish habitation. This is not only a question of making the polluted waters habitable but the question arises as to the effect of other environmental factors. A substance which is not present in amount sufficiently great to be fatal to the fish might be made to become so even by the addition of an antagonistic substance or substances provided that the proportions of the substances do not approximate a certain definite ratio. Experiments have been performed which show that calcium chloride (0.297 N.) is made more rapidly fatal by the addition of small amounts of sodum chloride although the amount of sodium chloride added alone would not be fatal. With 0.297 N. sodium chloride the addition of calcium chloride in small amounts decreases the rapidity of fatality of the sodium chloride until a certain

maximum effect is reached, i.e., when the proportion of the two salts is approximately 10% calcium chloride and 90% sodium chloride. This agrees fairly well with Osterhout's (1914) results on the antagonistic effect of these two salts on the growth in plants. This is especially important in the proposed treatment of polluted streams. In other words if the correct proportion of antagonizing substance is not added the effect might be detrimental rather than beneficial.

All these facts have important bearing on the problem dealing with the fish in relation to its environment. It is hoped that not only similar work will be undertaken not only with the different stages of the life history of the fish and that the most sensitive stage will be determined.

SUMMARY OF CONCLUSIONS

1. The toxicities of the chlorides of lithium, ammonium, sodium, calcium, magnesium, and barium to fish are increased with rise of temperature.
2. The effect of temperature on the toxicities of the chlorides of lithium and ammonium do not follow van't Hoff's rule in its entirety.
3. The relative toxicities of lithium chloride at different temperatures to the goldfish follow very closely the square root of relative standard metabolism of the goldfish as given by Krogh.
4. A close approximation of the relative deleterious effect of obnoxious substances to fish can be determined by comparing the constants of the equations of the theoretical velocity of fatality curves of the fish when killed in these substances. The resist-

ance of the fish to these deleterious substances can be determined by the same method since the resistance of the fish is the reciprocal of the deleterious effect of the substance on the fish.

5. The relative toxicities of sodium chloride, magnesium chloride, calcium chloride, and barium chloride to the blunt-nosed minnow (Pimephales notatus Raf.) are not the same as the relative conductance of these salts.

6. The relative resistance of Carassius carassius L., Pimephales notatus Raf., and Netropis blennius Gir., to ammonium chloride decreases in the order named.

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TABLE I.

The survival time and the velocity of fatality of goldfish in lithium chloride. Column 5 gives relative conductance.

Normal LiCl 4° C.	Weight of fish in grams	Survival time of fish in minutes	Velocity of fatality 100/t	Relative conductance
0.058	1.6	1411	0.07	1.27
"	2.0	1260	0.08	"
0.116	1.5	685	0.146	2.43
"	1.6	685	0.146	"
0.232	1.0	112	0.89	4.61
"	1.7	125	0.80	"
0.302	1.2	106	0.94	5.79
"	2.2	112	0.90	"
0.372	1.2	72	1.37	7.04
"	1.2	72	1.37	"
0.488	1.2	48	2.08	8.84
"	1.9	40	2.50	"
11.8°C.				
0.058	1.8	526	0.19	1.67
"	1.8	800	0.12	"
0.116	2.8	359	0.28	3.15
"	2.8	369	0.27	"
0.232	1.7	131	0.76	6.00
"	1.7	131	0.76	"
0.302	1.2	82	1.22	7.60
"	1.9	74	1.35	"
0.372	1.9	64	1.59	9.36
"	2.1	69	1.45	"
0.488	1.6	42	2.38	11.66
"	1.9	45	2.22	"
15.3°C.				
0.058	1.5	524	0.19	1.88
"	1.5	702	0.14	"
0.116	1.7	457	0.22	3.53
"	2.3	413	0.24	"
0.232	1.2	61	1.64	6.64
"	2.2	87	1.15	"
0.302	1.0	58	1.72	8.42
"	1.0	58	1.72	"
0.372	1.1	49	2.41	10.37
"	1.2	34	2.94	"

TABLE I Continued.

Normal LiCl 20° C.	Weight of fish in grams	Survival time of fish in minutes	Velocity of fatality 100/t	Relative conductance
0.046	1.0	544	0.18	1.68
0.058	1.4	410	0.24	2.20
"	1.5	803	0.12	"
0.093	1.1	152	0.66	3.18
"	2.7	213	0.47	"
0.116	1.3	192	0.52	3.99
"	1.3	255	0.39	"
0.151	1.2	75	1.34	5.09
"	1.2	80	1.25	"
0.232	0.9	57	1.76	7.44
"	1.4	81	1.23	"
"	1.0	35	2.86	7.45
"	1.0	36	2.78	"
0.267	1.4	34	2.94	8.45
"	1.4	35	2.86	"
0.302	1.2	46	2.17	9.44
"	1.4	46	2.17	"
0.418	1.2	30	3.33	12.53
"	1.4	31	3.52	"
0.488	1.6	35	2.81	14.37
"	1.6	35	2.81	"
24.9°C.				
0.058	1.9	322	0.31	2.31
"	2.3	466	0.21	"
0.116	1.3	152	0.66	4.43
"	1.3	157	0.64	"
0.232	1.3	337	2.73	8.40
"	1.3	38	2.62	"
0.302	1.5	27	3.72	10.54
"	2.3	36	2.79	"
0.372	1.1	23	4.34	13.30
"	2.1	25	4.00	"
29.8°C.				
0.046	0.9	224	0.45	2.09
"	1.4	244	0.41	"
0.058	1.3	224	0.45	2.53
"	1.5	263	0.38	"
0.093	1.1	98	1.02	3.94
"	1.6	98	1.02	"
0.116	1.1	110	0.91	4.91
"	1.6	124	0.81	"
0.151	1.1	44	2.27	6.20
"	1.4	49	2.02	"
0.232	1.1	25	4.00	9.32
"	2.0	36	2.78	"

TABLE I. Continued.

Normal LiCl 29.8°C.	Weight of fish in grams	Survival time of fish in minutes	Velocity of fatality 100/t	Relative conductance
0.267	1.2	19	5.26	10.30
"	1.4	16	6.25	"
0.302	1.6	22	4.55	11.66
"	2.0	36	2.78	"
0.337	1.1	14	7.14	12.70
"	1.6	17	5.88	"
0.372	1.3	17	5.88	13.71
"	2.3	18	5.56	"
0.488	1.3	10	10.00	17.70
34.8°C.				
0.046	1.4	17	5.88	2.32
"	1.7	50	2.00	"
0.058	1.3	32	3.63	2.79
"	1.3	41	2.42	"
0.116	1.2	37	2.73	5.31
"	1.4	61	1.64	"
0.232	1.1	10	10.00	10.45
"	1.3	15	6.67	"
0.302	1.0	8	12.50	12.80
"	1.9	8	12.50	"
0.372	1.3	7	14.28	14.71
"	1.7	8	12.50	"

TABLE II.

The ratio of increase in toxicity of lithium chloride to the goldfish, Carassius carassius L., with an increase of 10 degrees centigrade, approximately.

Normal	4.0° to 11.8° C.	4.0° to 15.1° C.	11.8° to 20.0° C.	15.1° to 25.3° C.	20.0° to 29.8° C.	25.3° to 34.8° C.
0.046	----	----	----	----	2.32	----
0.058	1.97	2.15	1.09	1.56	3.53	10.08
0.093	----	----	----	----	1.87	----
0.116	1.73	1.58	1.60	2.85	1.91	3.15
0.151	----	----	----	----	1.67	----
0.232	0.91	1.60	3.69	1.98	1.16	3.00
0.267	----	----	----	----	1.97	----
0.302	1.35	1.88	3.39	1.86	1.59	3.94
0.337	----	----	----	----	1.97	----
0.372	1.08	1.05	----	1.73	----	3.20
0.488	1.04	----	1.24	----	3.50	----
Averages	<u>1.35</u>	<u>1.65</u>	<u>2.20</u>	<u>2.00</u>	<u>2.15</u>	<u>4.67</u>

TABLE III.

The survival time and the velocity of fatality of the blunt-nosed minnow, Pimephales notatus (Raf.), in sodium chloride. Column 5 gives relative conductance.

Normal NaCl 12.8° C.	Weight of fish in grams	Survival time of fish in minutes	Velocity of fatality 100/t	Relative conductance
0.025	---*	21600* \pm	0.005	1.00
"	---*	21600* \pm	0.005	"
0.05	2.2	480	0.20	1.66
"	3.0	578	0.13	"
0.10	2.1	1529	0.06	3.33
"	3.3	710	0.14	"
0.227	1.4	310	0.33	7.12
"	1.9	236	0.42	"
0.25	1.8	116	0.86	7.72
"	2.5	118	0.85	"
0.275	1.6	131	0.77	8.48
"	1.7	131	0.77	"
0.302	2.4	111	0.90	9.22
"	2.4	100	1.00	"
0.333	1.2	69	1.45	10.37
"	1.9	91	1.10	"
17.8° C.				
0.025	2.6	7920	0.01	0.93
"				"
0.05	2.0	5902	0.02	1.95
"	3.3	1742	0.06	"
0.10	1.6	4236	0.02	3.75
"	2.4	21701	0.005	"
0.227	1.2	233	0.43	7.95
"	1.7	299	0.33	"
0.25	1.5	121	0.83	8.72
"	1.6	216	0.46	"
0.275	1.5	108	0.93	9.51
"	1.6	87	1.16	"
0.302	1.7	61	1.64	10.37
"	1.7	61	1.64	"
"	1.7	53	1.88	"
"	0.9	40	2.50	"
0.333	1.4	65	1.54	11.37
"	1.6	50	2.00	"

22.8° C.

0.025	1.8	8520 \pm	0.01	1.15
"	2.1	4920 \pm	0.02	"

In this and following tables the asterisk () indicates that after three days the temperature was raised to 18° to 20° C.

TABLE III Continued.

Normal NaCl 22.8° C.	Weight of fish in grams	Survival time of fish in minutes	Velocity of fatality 100/t	Relative conductance
0.05	1.6	14400 ±	0.002	2.18
"	2.4	3120	0.03	"
0.10	1.8	575	0.17	4.22
"	2.3	7920 ±	0.01	"
0.227	2.2	69	1.45	8.95
"	2.4	106	0.94	"
0.25	1.4	73	1.37	9.71
"	1.9	73	1.37	"
0.275	1.8	26	3.85	10.56
"	1.8	36	2.77	"
0.302	1.8	23	4.35	11.51
"	1.8	23	4.35	"
0.333	1.8	24	4.17	12.63
"	2.2	19	5.27	"
27.8° C.				
0.025	1.8	1400 ±	0.07	1.23
"	2.3	480 ±	0.21	"
0.05	1.7	1400 ±	0.07	2.42
"	3.6	480 ±	0.21	"
0.10	1.5	166	0.60	4.63
"	1.8	123	0.81	"
0.227	1.9	50	2.00	9.76
"	1.9	53	1.89	"
0.25	1.6	40	2.50	10.66
"	2.6	34	2.94	"
0.275	1.7	34	2.94	11.60
"	2.0	34	2.94	"
0.302	1.5	14	7.15	12.79
"	1.8	18	5.55	"
0.333	2.0	10	10.00	13.94
"	2.5	17	5.89	"
32.8° C.				
0.025	2.0	64	1.56	1.37
"	2.4	64	1.53	"
"	1.6	129	0.77	"
"	1.7	54	1.85	"
0.05	---	44	2.27	2.62
"	---	44	2.27	"
"	1.8	129	0.77	"
"	2.4	102	0.98	"
0.10	2.0	54	1.85	5.03
"	2.3	138	0.72	"

TABLE IV.

The survival time and the velocity of fatality of the blunt-nosed minnow, Pimephales notatus (Rafinesque), in magnesium chloride. Column 5 gives relative conductance.

Normal MgCl ₂ 12.8°C.	Weight of fish in grams	Survival time of fish in minutes	Velocity of fatality 100/t	Relative conductance
0.025	1.6	840*	0.12	0.85
"	2.5	7860*	0.01	"
0.05	2.9	7814**	0.01	1.60
"	3.5	3389**	0.03	"
0.10	2.1	6180*	0.02	3.06
"	2.3	23640*	0.004	"
0.227	1.7	86	1.16	6.36
"	1.9	78	1.28	"
0.25	2.0	105	0.95	6.91
"	3.5	112	0.89	"
0.275	1.6	115	0.87	7.49
0.302	1.6	72	1.39	8.12
"	1.9	53	1.89	"
0.333	1.5	69	1.43	8.94
"	1.7	100	1.00	"
17.8°C.				
0.025	2.1	16560**	0.00606	0.98
"	2.5	27360**	0.00369	0.98
0.05	2.4	28800**	0.00347	1.82
"	2.5	28800**	0.00347	"
0.10	1.8	4236	0.0236	3.44
"	3.5	15000	0.00667	"
0.227	1.5	173	0.58	7.33
"	1.9	99	1.01	"
0.25	1.6	114	0.88	7.85
"	1.7	78	1.28	"
0.275	0.6	56	1.79	8.44
"	3.0	74	1.35	"
0.302	0.6	57	1.75	9.29
"	3.7	65	1.54	"
0.333	0.9	40	2.50	10.12
"	1.7	53	1.89	"
22.8°C.				
0.025	1.8	4800±	0.0208	1.05
"	2.0	6200±	0.0161	"
0.05	2.5	3120±	0.0317	2.08
"	2.6	3120±	0.0317	"
0.10	2.7	160±	0.625	3.84

TABLE IV Continued.

Normal MgCl ₂ 22.8° C.	Weight of fish in grams	Survival time of fish in minutes	Velocity of fatality 100/t	Relative conductance
0.227	1.4	101	0.99	8.22
"	1.9	89	1.12	"
0.25	1.7	73	1.37	8.65
"	1.9	73	1.37	"
0.275	1.8	43	2.33	9.36
"	1.8	51	1.96	"
0.302	1.6	35	2.86	10.30
"	1.8	35	2.86	"
0.333	1.7	32	3.12	11.75
"	1.8	44	2.25	"
27.8° C.				
0.025	2.1	1709	0.06	1.17
"	2.1	2880	0.035	"
0.05	1.3	2763	0.035	2.23
"	2.6	480±	0.21	"
0.10	1.5	516	0.198	4.22
"	3.7	120	0.83	"
0.227	1.9	52	1.92	8.74
"	2.1	70	1.43	"
0.25	1.7	16	6.25	9.48
"	1.7	40	2.50	"
0.275	1.5	34	2.94	10.27
"	1.6	18	5.66	"
0.302	1.5	23	4.35	12.70
"	1.8	27	3.70	"
0.333	2.0	12	8.33	12.12
"	2.1	25	4.00	"
32.8° C.				
0.055	1.9	166	0.60	2.47
"	1.8	40	2.50	"
"	3.4	52	1.91	"
"	3.5	106	0.94	"
0.025	2.0	66	3.30	1.29
"	3.3	110	0.90	"
"	3.4	51	1.96	"
"	3.5	6	16.66	"
0.10	2.0	37	2.70	----
"	2.0	108	0.93	----

TABLE V.

The survival time and the velocity of fatality of the blunt-nosed minnow, Pimephales notatus Raf., in calcium chloride. Column 5 gives relative conductance.

Normal CaCl ₂ 12.8°C.	Weight of fish in grams	Survival time of fish in minutes	Velocity of fatality 100/t	Relative conductance
0.025	2.5	15600*±	0.006	0.899
"	3.1	15600*±	0.006	"
0.05	2.6	10560*	0.009	1.64
"				"
0.10	3.7	4311	0.02	3.00
"	---	7120±	0.01	"
0.227	1.6	351	0.28	6.51
"	3.0	1071	0.09	"
0.25	1.9	118	0.868	7.05
0.275	2.0	90	1.11	7.38
"	3.0	75	1.34	"
0.302	1.0	66	1.52	8.51
"	3.5	87	1.15	"
0.333	1.6	86	1.16	9.22
"	1.9	58	1.72	"
17.8°C.				
0.025	2.3	6660**±	0.015	0.98
"	3.3	6900**±	0.014	"
0.05	2.5	9360**	0.011	1.84
"	2.6	5040**	0.02	"
0.10	1.7	4490	0.02	3.53
"	2.5	4430	0.02	"
0.227	1.5	158	0.63	7.34
"	2.0	293	0.34	"
0.25	1.5	202	0.49	8.01
"	1.9	117	0.85	"
0.275	1.3	56	1.79	8.53
"	1.7	65	1.54	"
0.302	1.3	61	1.64	9.48
"	1.5	53	1.89	"
0.333	1.2	40	2.50	10.50
"	1.5	32	3.13	"
22.8°C.				
0.025	2.3	2580	0.04	1.14
"	2.6	7920±	0.01	"
0.05	2.2	5760±	0.027	---
"	2.3	1600±	0.06	---
0.10	2.1	1140±	0.08	3.83
"	2.3	5915	0.016	"
0.227	1.8	73	1.37	7.85
"	2.1	73	1.37	"

TABLE V Continued.

Normal CaCl ₂ 22.8°C.	Weight of fish in grams	Survival time of fish in minutes	Velocity of fatality 100/t	Relative conductance
0.25	1.3	72	1.39	8.92
"	1.5	81	1.23	"
0.275	1.5	55	1.82	9.52
"	1.8	52	1.89	"
0.302	2.0	30	3.33	10.60
"	2.3	47	2.13	"
0.333	1.3	32	3.13	-----
"	1.9	26	3.85	-----
22.8°C.				
0.025	1.9	2800	0.035	1.19
"	2.2	580	0.17	"
0.05	2.0	480±	0.21	2.29
"	1.8	1200±	0.08	"
"	2.3	1200±	0.08	"
"	3.4	480±	0.21	"
0.10	2.0	248	0.40	4.29
"	2.3	1100	0.09	"
0.227	1.8	60	1.66	8.31
"	2.2	49	2.04	"
0.25	1.2	40	2.50	9.83
"	2.6	34	2.94	"
0.275	1.7	34	2.94	11.60
"	2.0	34	2.94	"
0.302	1.5	14	7.15	12.93
"	1.8	18	5.55	"
0.333	2.0	10	10.00	13.94
"	2.5	17	5.89	"
32.8°C.				
0.025	1.6	84	1.19	1.32
"	1.8	81	1.23	"
"	2.0	64	1.58	"
"	2.5	46	2.17	"
0.05	1.7	66	1.51	2.51
"	1.6	84	1.19	"
"	1.8	96	1.04	"
"	2.0	87	1.15	"
0.10	1.7	49	2.04	4.49
"	2.2	179	0.56	"
0.227	1.6	37	2.70	9.54
"	1.7	51	1.96	"

TABLE VI.

The survival time and the velocity of fatality of the blunt-nosed minnow, Pimephales notatus Raf., in barium chloride. Column 5 gives relative conductance.

Normal BaCl ₂ 12.8°C.	Weight of fish in grams	Survival time of fish in minutes	Velocity of fatality 100/t	Relative conductance
0.025	---	520 \pm	0.19	0.82
"	---	520 \pm	0.19	"
0.05	2.1	86	1.16	1.61
"	2.2	120	0.83	"
0.10	2.0	54	1.85	3.01
"	2.0	54	1.85	"
0.227	1.9	31	3.23	6.37
"	2.3	36	2.78	"
0.25	2.0	35	1.90	6.98
"	3.5	37	1.82	"
0.275	1.5	33	2.20	7.64
"	1.7	33	2.20	"
0.302	1.8	26	2.57	8.30
"	1.8	26	2.57	"
0.333	1.6	20	4.50	9.07
"	1.9	23	4.35	"
17.8°C.				
0.025	0.9	135	0.74	0.95
"	3.4	135	0.74	"
0.05	1.1	107	0.93	1.81
"	1.2	96	1.04	"
0.227	0.5	14	7.14	7.23
"	2.0	32	3.13	"
0.25	0.8	19	5.26	7.88
"	4.2	22	4.55	"
0.275	0.9	21	4.77	8.51
"	4.2	17	5.88	"
0.302	0.6	17	5.88	9.34
"	0.6	17	5.88	"
0.333	0.5	6	16.66	----
"	2.7	14	7.14	----
22.8°C.				
0.025	2.2	420 \pm	0.24	1.09
"				
0.05	1.5	69	1.45	2.18
"	2.2	69	1.45	"
"	2.3	71	1.41	"
"	3.0	40	2.50	"
0.10	1.4	32	3.13	3.82
"	2.3	38	2.63	"

TABLE VI Continued.

Normal BaCl ₂ 22.8°C.	Weight of fish in grams	Survival time of fish in minutes	Velocity of fatality 100/t	Relative conductance
0.227	1.6	13	7.69	7.99
"	1.7	13	7.69	"
0.25	1.5	11	9.09	8.65
"	2.0	11	9.09	"
0.275	2.2	9	11.10	9.38
"	2.3	8	12.50	"
0.302	2.0	10	10.00	10.36
"	2.3	10	10.00	"
0.333	1.8	10	10.00	11.27
"	2.3	7	7.43	"
27.8°C.				
0.025	2.6	73	1.37	1.18
"	3.3	42	2.38	"
0.05	2.2	39±	2.56	2.21
"	3.4	39±	2.56	"
0.10	2.0	7.5	13.35	4.22
"	3.5	6.5	15.39	"
0.227	2.2	6.5	15.38	8.81
"	2.2	6.5	15.38	"
0.25	2.2	5.5	18.19	9.62
"	3.5	5.5	18.91	"
0.275	2.0	4.5	22.22	---
"	2.0	7.5	13.35	"
0.302	2.1	4.5	22.22	11.43
"	2.3	4.5	22.22	"
0.333	1.5	3.5	28.59	12.37
"	1.6	3.5	28.59	"
32.8°C.				
0.025	1.5	20	5.00	1.30
"	2.0	13	7.69	"
0.05	1.6	50	2.00	5.30
"	1.7	11	9.09	"

TABLE VII.

63.

The ratio of increase in toxicity of electrolytes to the blunt-nosed minnow, Pimephales notatus Raf., with an increase of 10 degrees centigrade.

Substance	Noram1	12.8° to 22.8° C.	17.8° to 27.8° C.	22.8° to 32.8° C.	
NaCl	0.025	3.22	4.2	86.5	
"	0.05	0.17	4.05	110.0	
"	0.10	0.26	8.96	46.1	
"	0.227	3.25	5.16	----	
"	0.25	1.56	4.56	----	
"	0.275	3.61	3.41	----	
"	0.302	4.58	2.99	----	
"	0.333	3.72	4.26	----	
		<u>2.55</u>	<u>4.69</u>	<u>80.86</u>	Averages.
CaCl ₂	0.025	2.99	4.02	7.59	
"	0.05	2.87	8.56	9.49	
"	0.10	1.62	6.62	3.35	
"	0.227	9.67*	4.14	1.76	
"	0.25	1.55	2.32	----	
"	0.275	1.54	1.79	----	
"	0.302	2.08	3.57	----	
"	0.333	2.76	2.63	----	
		<u>3.13</u>	<u>4.20</u>	<u>5.55</u>	Averages.
		2.29			Average.
BaCl ₂	0.025	1.24	2.34	25.4	
"	0.05	1.67	2.60	2.03	
"	0.10	1.55	2.22	----	
"	0.227	2.57	3.53	----	
"	0.25	3.27	3.73	----	
"	0.275	3.88	5.17*	----	
"	0.302	2.60	3.77	----	
"	0.333	2.53	2.85	----	
		<u>2.81</u>	<u>3.43</u>	<u>13.71</u>	Averages.
			3.14		Average.
MgCl ₂	0.025	0.87	9.59*	94.8	
"	0.05	1.78	17.75*	34.2	
"	0.10	93.60*	3.20	2.2	
"	0.227	0.86	2.24	----	
"	0.25	1.47	3.43	----	
"	0.275	2.44	2.38	----	
"	0.302	1.78	2.41	----	
"	0.333	2.22	2.51	----	
		<u>13.13</u>	<u>5.44</u>	<u>4.37</u>	Averages.
		1.63	2.69		

The ratios marked with an asterisk (*) have been omitted in the second set of averages.

TABLE VIII.

The relative conductance of NaCl, CaCl₂, BaCl₂, and MgCl₂.

Substance	Normal	12.8° C.	17.8° C.	22.8° C.	27.8° C.	32.8° C.
NaCl	0.025	0.91	1.00	1.15	1.23	1.37
CaCl ₂	"	0.90	0.985	1.14	1.19	1.37
BaCl ₂	"	0.82	0.95	1.09	1.18	1.30
MgCl ₂	"	0.85	0.98	1.05	1.17	1.29
NaCl	0.05	1.66	1.95	2.18	2.42	2.62
CaCl ₂	"	1.64	1.84	----	2.29	2.51
BaCl ₂	"	1.61	1.81	2.18	2.21	2.47
MgCl ₂	"	1.60	1.82	2.04	2.23	2.47
NaCl	0.10	3.33	3.75	4.22	4.63	5.03
CaCl ₂	"	3.00	3.53	3.83	4.29	4.60
BaCl ₂	"	3.01	----	3.82	4.22	----
MgCl ₂	"	3.06	3.44	3.84	4.22	----
NaCl	0.227	7.12	7.95	8.95	9.76	----
CaCl ₂	"	6.51	7.34	7.85	8.80	----
BaCl ₂	"	6.37	7.23	7.99	8.81	----
MgCl ₂	0. "	6.36	7.33	8.00	8.74	----
NaCl	0.25	7.72	8.72	9.71	10.66	----
CaCl ₂	"	7.05	8.01	8.92	9.83	----
BaCl ₂	"	6.98	7.88	8.65	9.62	----
MgCl ₂	"	6.90	7.85	8.00	9.48	----
NaCl	0.275	8.48	9.51	10.66	11.60	----
CaCl ₂	"	7.38	8.53	9.52	11.60	----
BaCl ₂	"	7.64	8.51	9.38	----	----
MgCl ₂	"	7.49	8.44	9.36	10.27	----
NaCl	0.302	9.22	10.37	11.51	12.93	----
CaCl ₂	"	8.51	9.48	10.60	12.93	----
BaCl ₂	"	8.30	9.34	10.36	12.37	----
MgCl ₂	"	8.12	9.29	10.30	11.30	----
NaCl	0.333	10.37	11.37	12.63	13.94	----
CaCl ₂	"	9.22	10.50	----	13.94	----
BaCl ₂	"	9.07	----	11.27	----	----
MgCl ₂	"	8.94	10.12	11.30	12.12	----

TABLE IX.

The survival time and the velocity of fatality of the blunt-nosed minnow, Pimephales notatus Raf., in ammonium chloride.

Normal NH ₄ Cl 14.2° C.	Weight of fish in grams	Survival time of Fish in minutes	Velocity of fatality 100/t
0.00505	After 30000	minutes.	Experiment discontinued. Fish alive.
"	"	"	"
0.00555	4.4	7000±	0.014
"	After 30000	minutes.	Experiment discontinued. Fish alive.
0.00606	3.0	6580±	0.015
"	3.0	7200±	0.014
0.00656	2.4	11520±	0.008
"	2.2	24400±	0.004
0.00707	2.5	10320±	0.009
"	2.8	7200±	0.014
0.00757	2.8	10300±	0.009
"	2.8	10580±	0.009
0.00808	2.7	7980±	0.012
"	2.7	9240±	0.011
0.00858	2.4	28600±	0.003
"	3.5	5040±	0.02
0.00909	2.9	6480±	0.014
"	3.6	6480±	0.014
0.00959	2.7	2580±	0.038
"	3.0	2880±	0.034
0.0101	2.7	5700±	0.017
"	4.4	8640±	0.011
0.0111	2.9	4320±	0.023
"			
0.0121	3.2	4080±	0.024
"	2.8	420±	0.23
0.0137	2.7	2520±	0.04
"	3.2	4020±	0.025
0.0151	2.7	2460±	0.04
"	3.0	3439	0.029
0.0171	2.7	1399	0.07
"	2.7	3600±	0.02
0.0192	2.4	1367	0.07
"	3.0	2160	0.046
0.0242	2.0	802	0.12
"	2.8	727	0.14
0.0303	2.1	211	0.47
"	2.5	521	0.19
0.0374	2.5	117	0.85
"	2.8	106	0.94
0.0464	2.4	76	1.32
"	2.6	102	0.98
0.0525	2.4	90	1.11
"	2.4	95	1.05

TABLE IX Continued.

Normal NH ₄ Cl 14.2° C.	Weight of fish in grams	Survival time of fish in minutes	Velocity of fatality 100/t
0.0616	2.0	60 ⁿ	1.66
"	2.6	101	0.99
0.0787	2.0	58	1.72
"	2.0	58	1.72
0.0928	2.7	68	1.47
"	3.0	65	1.54

TABLE X.

The survival time and the velocity of fatality of the blunt-nosed minnow, Pimephales notatus Raf., in ammonium chloride.

Normal NH ₄ Cl 19.8° C.	Weight of fish in grams	Survival time of fish in minutes	Velocity of fatality 100/t
0.006	1.9	7000 \pm	0.014
"	1.6	5100 \pm	0.019
0.0065	2.0	249	0.40
"	2.0	281	0.36
0.0071	2.0	247	0.40
"	2.0	340	0.29
0.0076	1.4	4140 \pm	0.024
"	1.6	6085	0.016
0.0081	1.9	397	0.25
"	2.0	498	0.26
0.0086	1.3	3563 \pm	0.028
"	2.2	3563 \pm	0.028
0.0091	2.0	189	0.39
"	2.1	278	0.52
0.0096	1.9	258	0.39
"	2.0	294	0.34
0.0101	1.7	4782	0.02
"	1.9	447	0.22
0.0111	1.7	245	0.41
"	2.0	432	0.23
0.0121	1.7	269	0.37
"	2.1	1140 \pm	0.08
0.0136	2.1	1140 \pm	0.08
"	2.2	2730 \pm	0.04
0.0151	1.4	430	0.23
"	1.9	430	0.23
0.0192	1.9	270	0.37
"	2.0	137	0.73
0.0242	1.6	203	0.49
"	1.7	336	0.30
0.0303	1.6	136	0.74
"	1.9	237	0.42
0.0374	1.9	171	0.58
"	2.0	171	0.58
0.0464	2.0	69	1.45
"	2.0	70	1.42
0.0525	1.7	49	2.02
"	1.9	60	1.66
0.0616	1.8	48	2.08
"	1.8	49	2.02
0.0787	1.4	45	2.22
"	2.2	45	2.22

TABLE XI.

The survival time and the velocity of fatality of the blunt-nosed minnow, Pimephales notatus Raf., in ammonium chloride.

Normal NH ₄ Cl 24.9° C.	Weight of fish in grams.	Survival time of fish in minutes	Velocity of fatality 100/t
0.0061	2.0	519 ±	0.19
"	2.0	2709 ±	0.04
0.0065	1.6	519 ±	0.19
"	2.8	2709 ±	0.04
0.0071	2.4	4020	0.02
"	3.1	279	0.36
0.0076	1.6	279	0.36
"	3.6	286	0.25
0.0081	2.0	322	0.31
"	2.0	2768	0.04
0.0086	1.8	1016	0.09
"		1196	0.06
0.0091	1.9	1607	0.06
"	2.2	2662	0.04
0.0096	2.2	167	0.59
"	2.2	258	0.39
0.0101	1.9	253	0.39
"	2.0	530	0.19
0.0111	1.9	227	0.44
"	2.1	2660	0.04
0.0121	1.5	269	0.37
"	2.1	59	1.69
0.0137	2.3	185	0.54
"	2.3	239	0.42
0.0151	1.7	143	0.70
"	3.2	139	0.72
0.0171	2.0	174	0.57
"	2.2	400	0.25
0.0192	1.8	169	0.59
"	2.9	110	0.91
0.0242	1.5	131	0.76
"	2.8	116	0.85
0.0303	1.9	62	1.61
"	2.0	86	1.16
0.0374	1.7	47	2.12
"	1.8	47	2.12
0.0464	1.8	46	2.17
"	1.8	59	1.89
0.0525	1.8	30	3.33
"	1.8	47	2.12
0.0616	1.6	26	3.85
"	1.9	28	3.57
0.0787	1.7	26	3.86
"	1.7	29	3.45

TABLE XII.

The survival time and the velocity of fatality of the straw-colored minnow, *Notropis blennius* (Gir.), in ammonium chloride. Column 5 gives relative conductance.

Normal NH ₄ Cl 15.5° C.	Weight of fish in grams	Survival time of fish in minutes	Velocity of fatality 100/t	Relative conductance
0.0084	---	7200	0.01	0.03
0.017	1.3	860 \pm	0.12	0.07
"	1.3	860 \pm	0.12	"
"	---	602	0.17	"
0.034	1.2	190	0.53	0.15
"	1.4	241	0.41	"
"	---	241	0.41	"
"	---	321	0.31	"
0.050	1.2	190	0.53	0.21
"	1.4	160	0.63	"
0.067	1.4	122	0.82	0.27
"	1.5	300 \pm	0.33	"
0.073	0.8	75	1.33	0.30
"	1.1	91	1.10	"
0.100	0.9	64	1.56	0.40
"	1.0	56	1.78	"
"	1.2	57	1.75	"
"	1.6	65	1.54	"
0.135	1.0	37	2.70	0.55
"	1.0	41	2.44	"
"	1.1	37	2.70	"
"	1.3	41	2.44	"
0.168	1.0	25	4.00	0.70
"	1.1	25	4.00	"
"	1.2	40	2.50	"
"	1.3	40	2.50	"
0.202	1.5	40	2.50	0.77
"	1.5	39	2.56	"
0.235	1.0	19	5.26	0.85
"	1.1	18	5.56	"
0.252	1.6	16	6.25	0.96
"	2.2	18	5.56	"
0.269	1.0	18	5.56	1.07
"	1.2	18	5.56	"
"	1.2	17	5.89	"
"	1.5	17	5.89	"
0.336	0.7	9	11.11	1.35
"	1.0	9	11.11	"
"	1.4	17	5.89	"
"	1.5	17	5.89	"
0.404	0.9	8	12.50	1.45
"	1.2	8	11.11	"
0.470	1.0	8	12.50	1.82
"	1.2	8	12.50	"

TABLE XIII.

The survival time and the velocity of fatality of the straw-colored minnow, Notropis blennius Gir., in ammonium chloride.

Normal NH ₄ Cl 19.8° C.	Weight of fish in grams	Survival time of fish in minutes	Velocity of fatality 100/t	
0.001	?	Alive after	50500 minutes.	Expt. discontinued.
"	?	"	"	"
0.0015	?	"	"	"
"	?	"	"	"
0.002	2.1	6120	0.016	
"	?	Alive after	50500 minutes.	Expt. discontinued.
0.003	2.8	6420	0.015	
"	2.8	6420	0.015	
0.004	3.4	6420	0.015	
"	?	30240 ±	0.008	
0.005	?	18720 ±	0.006	
"	?	18720 ±	0.006	
0.0075	4.2	6240	0.016	
"	?	28800	0.003	
0.012	1.0	907	0.113	
"	3.2	387	0.26	
0.015	1.6	131	0.76	
"	1.6	216	0.46	
0.019	2.7	141	0.71	
"	3.1	96	1.04	
0.024	0.7	431	0.23	
"	1.8	101	0.99	
0.030	1.2	62	1.61	
"	1.1	56	1.80	
0.037	0.6	64	1.56	
"	1.2	52	1.92	
0.046	0.8	123	0.81	
"	1.3	58	1.72	
0.053	1.3	78	1.26	
"	1.8	48	2.04	
0.062	1.0	42	2.38	
"	2.2	53	1.85	
0.079	1.8	47	2.38	
"	2.3	33	3.03	
0.101	1.3	25	4.00	
"	2.2	39	2.57	
0.126	0.6	32	3.13	
"	1.3	32	3.13	
0.161	1.2	20	5.00	
"	1.5	29	3.45	
0.202	1.3	18	5.56	
"	2.3	17	5.88	
0.252	1.9	16	6.25	
"	3.1	20	5.00	
0.303	0.9	11	9.09	
"	2.6	12	8.66	
0.353	1.1	8	12.50	
"	1.1	8	12.50	

TABLE XIII Continued.

Normal NH ₄ Cl 19.8°C.	Weight of fish in grams	Survival time of fish in minutes	Velocity of fatality 100/t
0.404	0.9	7	14.28
"	2.3	7	14.28
0.505	0.9	3	33.33
" "	1.5	5	20.00
0.555	0.7	2	50.00
"	2.2	3	33.33
0.606	1.1	2	50.00
"	1.1	2	50.00

TABLE XIV.

The Q_{10} of toxicity of lithium chloride to goldfish. The calculations are based upon the temperature toxicity curve of lithium chloride to goldfish. Figure 12.

Temperatures Centigrade.	The Q_{10}
4° to 14°	1.39
6° to 16°	1.47
8° to 18°	1.53
10° to 20°	1.59
12° to 22°	1.64
14° to 24°	1.66
16° to 26°	1.67
18° to 28°	1.70
20° to 30°	1.75
22° to 32°	1.90
24° to 34°	2.23

TABLE XV.

Table showing the ratio of the square root of the temperature standard metabolism curve of vertebrates as given by Krogh (1914) to the temperature toxicity curve of lithium chloride of the goldfish.

Temperature Centigrade	Ratio
4°	1.89
6°	1.89
8°	1.72
10°	1.66
12°	1.56
14°	1.55
16°	1.55
18°	1.55
20°	1.58
22°	1.63
24°	1.64
26°	1.71
28°	1.71

TABLE XVI.

71.

Temperature coefficient of the duration of life of
Imagoes Males and females fed on "glucose-agar".

Temperature C.	Duration of life of imago	Rate($\frac{100}{t}$)	Q ₁₀
	20th to 22nd gen- eration.		
	Days		
10°	120.5	0.83	1.70
15°	92.4	1.08	5.25
20°	40.2	2.49	1.99
25°	28.5	3.51	4.4
30°	13.6	7.35	
	30th to 32nd gen- eration		
27.5°	11.1	9.00	3.3
31.5°	6.87	14.55	630
33.1°	2.41	41.50	137
35°	0.95	105.2	10 ⁶
37.5°	0.032	3,125.0	

Table X.
Total duration of life

TEMPERATURE	Total duration of life	Rate($\frac{100}{t}$)	Q ₁₀
C.	Days		
15°	123.9	0.81	5.0
20°	54.3	1.84	3.0
25°	38.5	2.67	3.0
30°	21.15	4.65	

TABLE XVII.

This table is made up of two tables taken from Lillie (1917). The two tables were formulated by Lillie from data which he obtained by determining the time of exposure required by starfish eggs to 0.006 N. butyric acid to activate them at different temperatures.

Table II.
Group A. (June 9-12).

Number and date of series	Temperature of solution and optimum exposure	Mean optimum	Value of Q_{10}
2. June 9	8°:35-40 min. 18°: 9-12 min.	37.5 m. 10.5 m.	3.55
6. June 12	8°:36-40 min. 10°:32-36 min.	38 m. 34 m.	1.75
3. June 9	10°:26-30 min. 12°:22-26 min.	28 m. 24 m.	2.2
4. June 10	14°:22-24 min. 16°:18-20 min. 18°:ca.14 min.	23 m. 19 m. 14 m.	2.6 4.65
7. June 12	20°: 9 min. 22°: 6- 7 min. 24°: 4 min.	9 m. 6.5 m. 4 m.	5.0 11.6

Group B. (June 22-26).

23. June 26	8°:21-24 min. 10°:18-21 min.	22.5 m. 19.5 m.	2.0
22. June 26	12°: 8-14 min. 14°: 8-10 min. 16°: 6- 8 min.	11 m. 9 m. 7 m.	2.7 3.55
21. June 24	18°: 5- 6 min. 20°: 3- 5 min. 22°:2.5-3 min. 24°:1.5-2 min.	5.5 4 m. 2.75m. 1.75m.	5.0 6.4 9.5
17. June 22	24°: 2 min. 26°:1-1.5 min.	2 m. 1.25m.	10.5
20. June 24	26°:ca. 1 min. 28°:ca..5 min.	1 m. .5 m.	32.0

Table III.

Interval	Values of Q_{10}	
	A. June 9-12.	B. June 22-26.
8°-10°	1.75	2.0
10°-12°	2.2	
12°-14°		2.7
14°-16°	2.6	3.55
16°-18°	4.65	
18°-20°		5.0
20°-22°	5.0	6.4
22°-24°	11.6	9.5
24°-26°		10.5
26°-28°		32.0

TABLE XVIII.

The survival time and the velocity of fatality of the blunt-nosed minnow, Pimephales notatus Raf., when killed in 0.297 N. calcium chloride to which different amounts of sodium chloride have been added. Column one shows the normality of the sodium chloride in the 0.297^N calcium chloride solution.

Normality of NaCl 20° C.	Weight of fish in grams	Survival time of fish in minutes	Velocity of fatality 100/t
0.00	1.2	35	2.86
"	1.6	61	1.64
"	1.8	61	1.64
"	2.3	61	1.64
0.00036	2.0	53	1.88
"	2.1	53	1.88
0.00074	1.7	62	1.61
"	1.7	68	1.47
0.00148	1.8	34	2.94
"	3.1	31	3.22
0.00297	1.4	70	1.42
"	1.5	50	2.00
0.00594	1.6	65	1.54
"	2.0	52	1.92
0.0119	1.8	73	1.37
"	1.9	38	2.63
0.02376	1.5	99	1.01
"	2.0	54	1.85
0.0445	1.7	34	2.95
"	2.5	29	3.45
0.0817	1.4	47	2.13
"	1.6	39	2.56
0.119	1.5	51	1.96
"	1.6	28	3.57
0.156	1.3	26	3.85
"	1.6	46	2.17
0.230	1.6	31	3.22
"	2.2	38	2.63

TABLE XIX.

The survival time and the velocity of fatality of the blunt-nosed minnow, Pimephales notatus Raf., when killed in 0.297 N. sodium chloride to which different amounts of calcium chloride have been added. Column one shows the normality of the calcium chloride in the 0.297 N. sodium chloride solution.

Normality of CaCl_2 20° C.	Weight of fish in grams	Survival time of fish in minutes	Velocity of fatality 100/t
0.000	1.5	50	2.00
"	1.5	67	1.49
"	1.7	41	2.44
"	1.8	59	1.69
"	2.2	65	1.54
"	2.9	48	2.08
0.00036	2.0	64	1.56
"	2.2	64	1.56
0.00074	1.7	84	1.19
"	1.8	55	1.82
0.00148	1.3	44	2.22
"	1.7	66	1.51
0.00297	1.6	57	1.75
"	1.6	60	1.66
0.00594	1.7	66	1.51
"	1.8	78	1.28
0.0119	1.5	85	1.17
"	1.8	78	1.28
0.0237	1.6	82	1.22
"	2.3	111	0.90
0.0445	1.6	75	1.33
"	1.7	73	1.37
0.0817	1.6	54	1.85
"	1.7	68	1.46
0.119	1.6	59	1.69
"	1.7	75	1.45
0.156	2.0	46	2.17
"	2.0	55	1.82
0.193	1.6	33	3.03
"	2.2	33	3.03
0.230	1.7	29	3.45
"	2.2	22	4.55
0.267	1.4	20	5.00
"	1.4	21	4.76
0.297	1.7	23	4.35
"	1.7	20	5.00
"	1.7	21	4.76
"	1.8	20	5.00

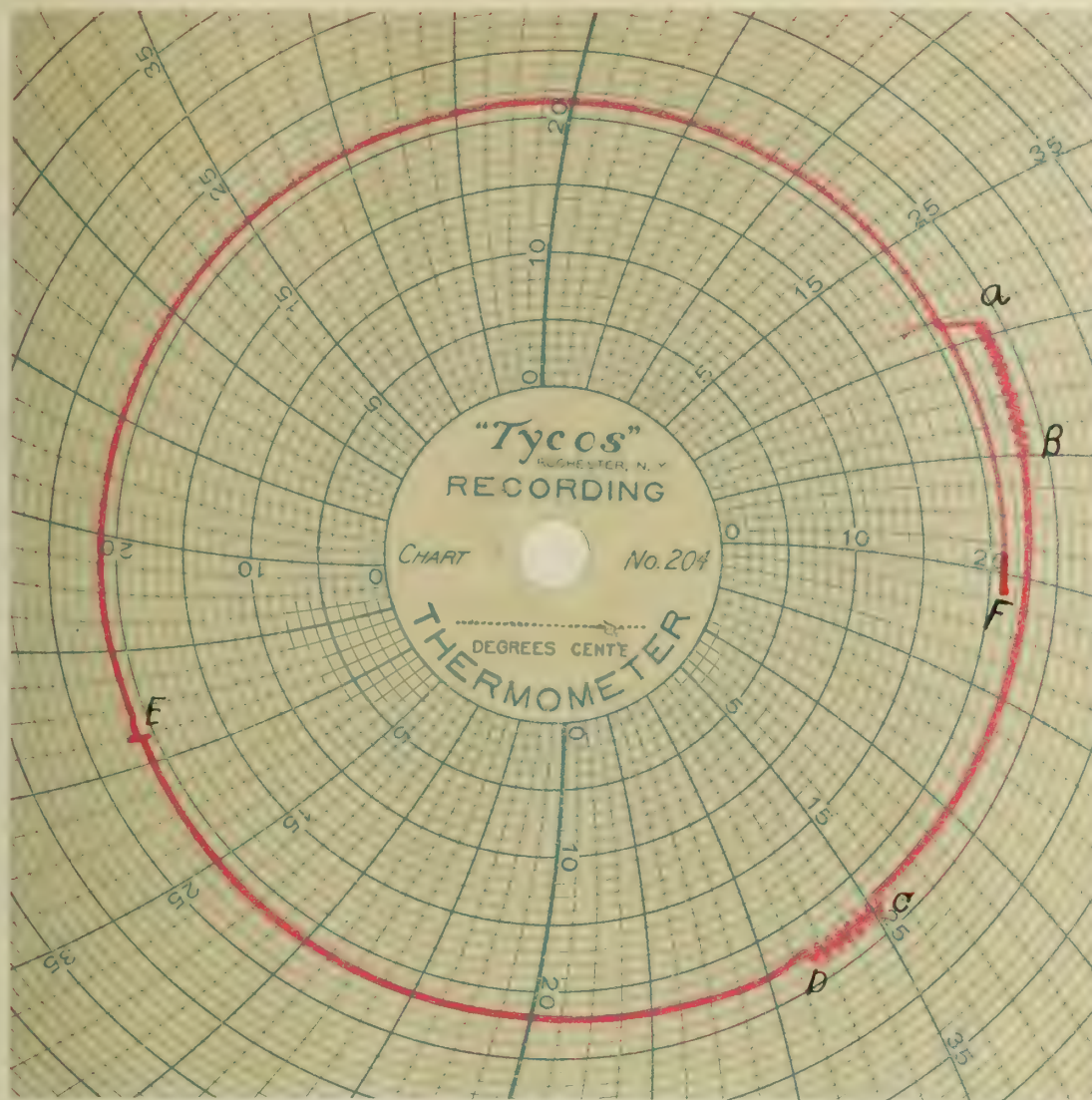


Figure 1. A Tyccos recording thermometer record of the constant temperature bath showing the variation in temperature, A to B and C to D, when the inflow of hot and cold water is large the flow of and the slight variation in temperature when the hot and cold water is very small, E to F. The disk makes one complete revolution every twenty four hours.

Figure 2. Graph showing the velocity of fatality curve, CABG, and the theoretical velocity of fatality curve, PABF, of the blunt-nosed minnow (Pimephales notatus Raf.) when killed in ammonium chloride. LIJM is the survival time curve and HIJK is the theoretical survival time curve. Ordinate represents survival time in minutes at left of figure and velocity of fatality at right of figure. Abscissa represents concentration of ammonium chloride. One block = 0.008 N. The plus signs (+) represent survival time of individual fish and the circles (•) represent the velocity of fatality.

Minutes

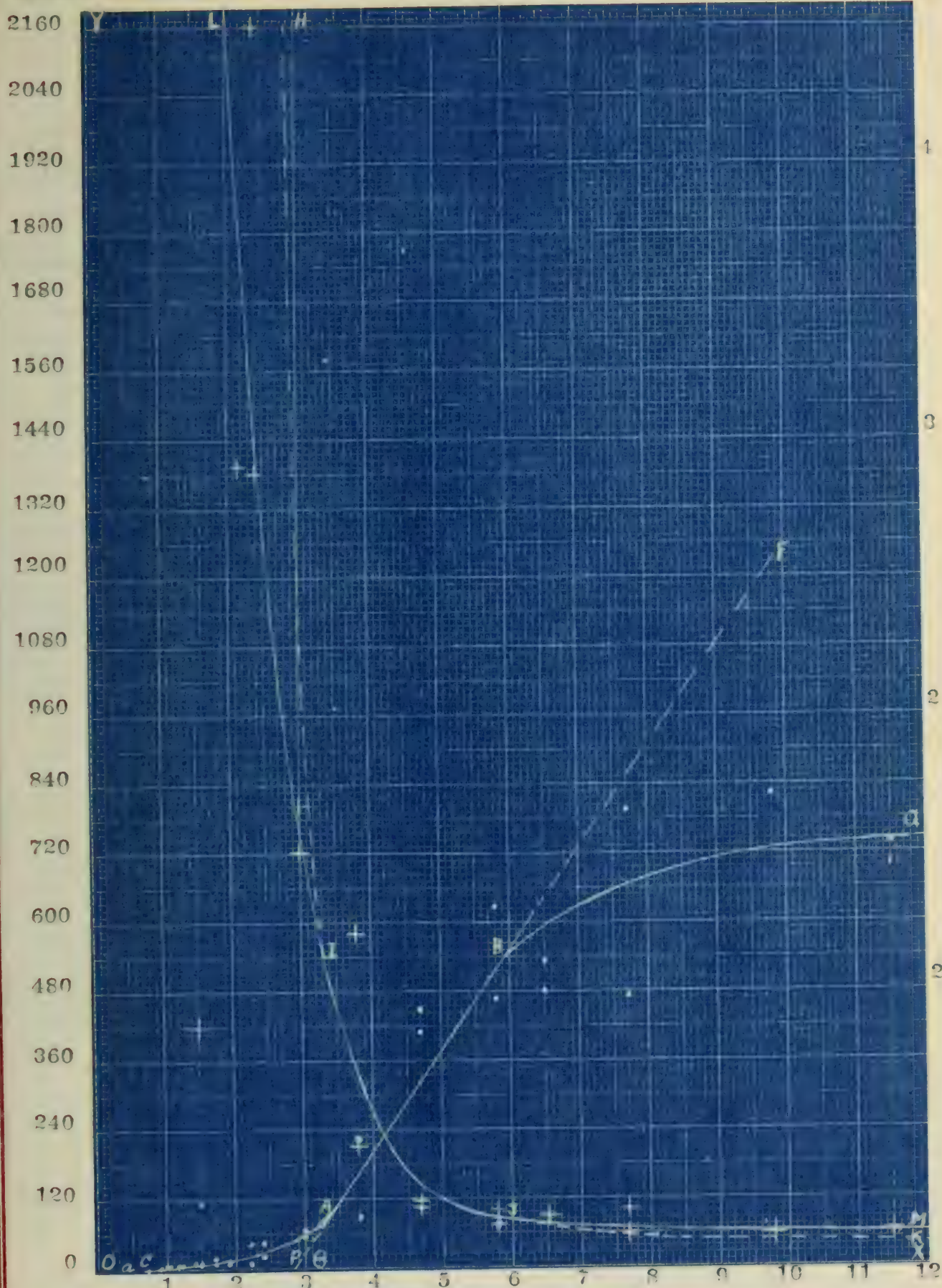
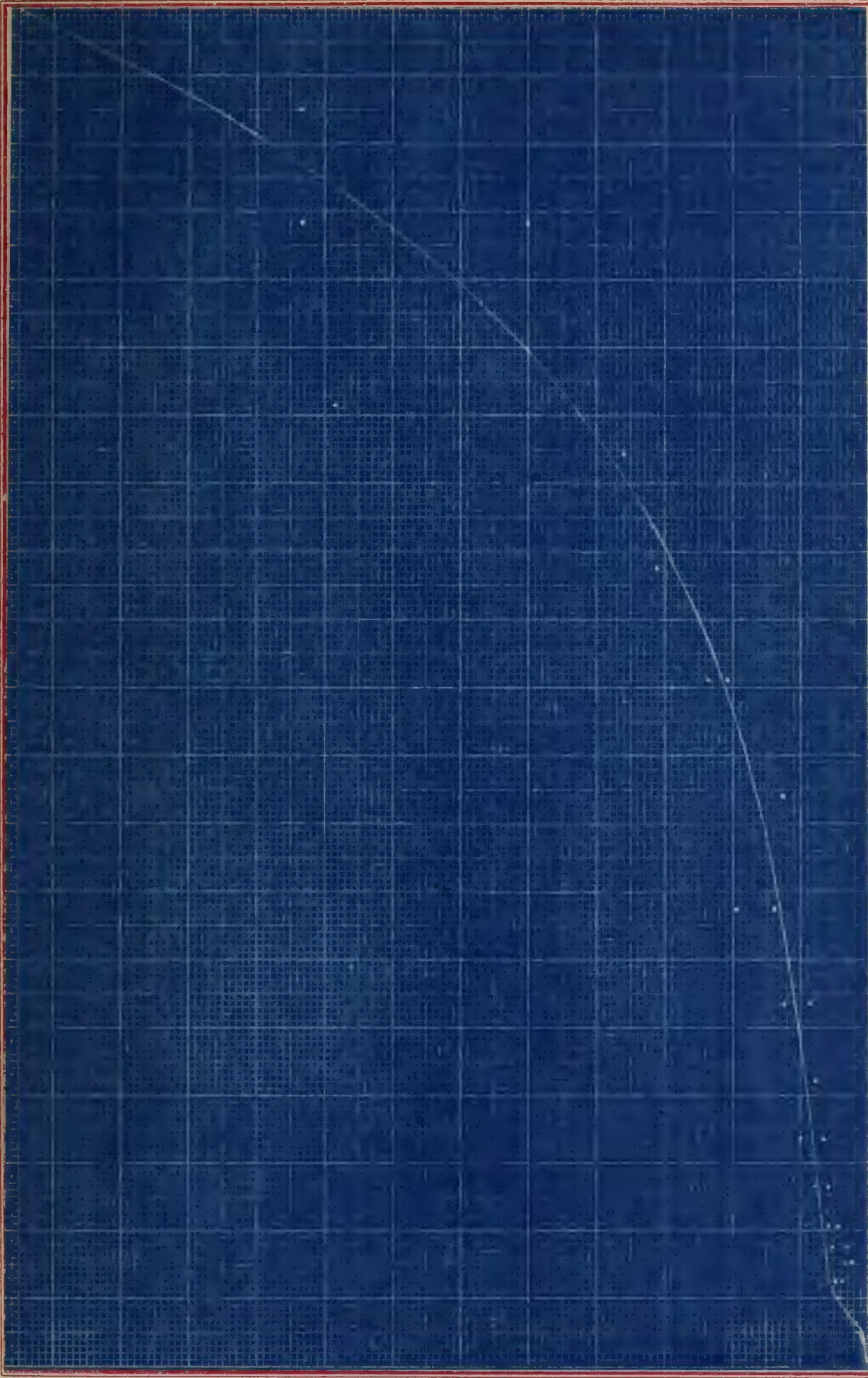


Figure 2.

Figure 3. Graph showing the velocity of fatality curve of the straw-colored minnow, Notropis blennius Gir., when killed in a very large range of concentrations of ammonium chloride. One block ordinate represents four units of velocity of fatality and one block abscissa represents 0.03 N. ammonium chloride.

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19

Figure 3.



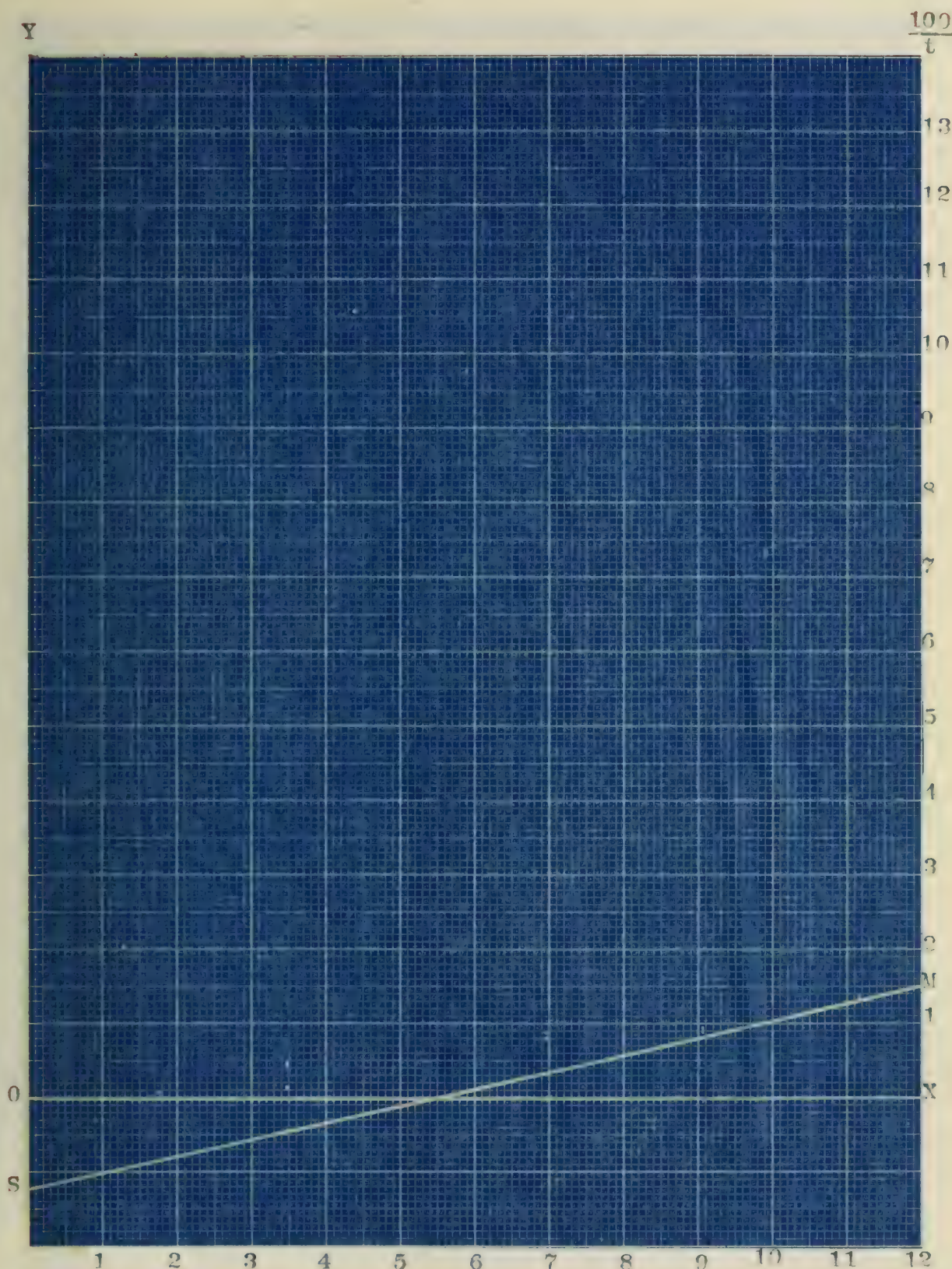


Figure 4. Graph showing the theoretical velocity of fatality curve of the goldfish when killed in lithium chloride solution at 10°C . Ordinate represents velocity of fatality and abscissa represents concentration of the lithium chloride solution. One block abscissa = 0.0333 N. lithium chloride. The circles (•) represent velocity of fatality of individual fish.

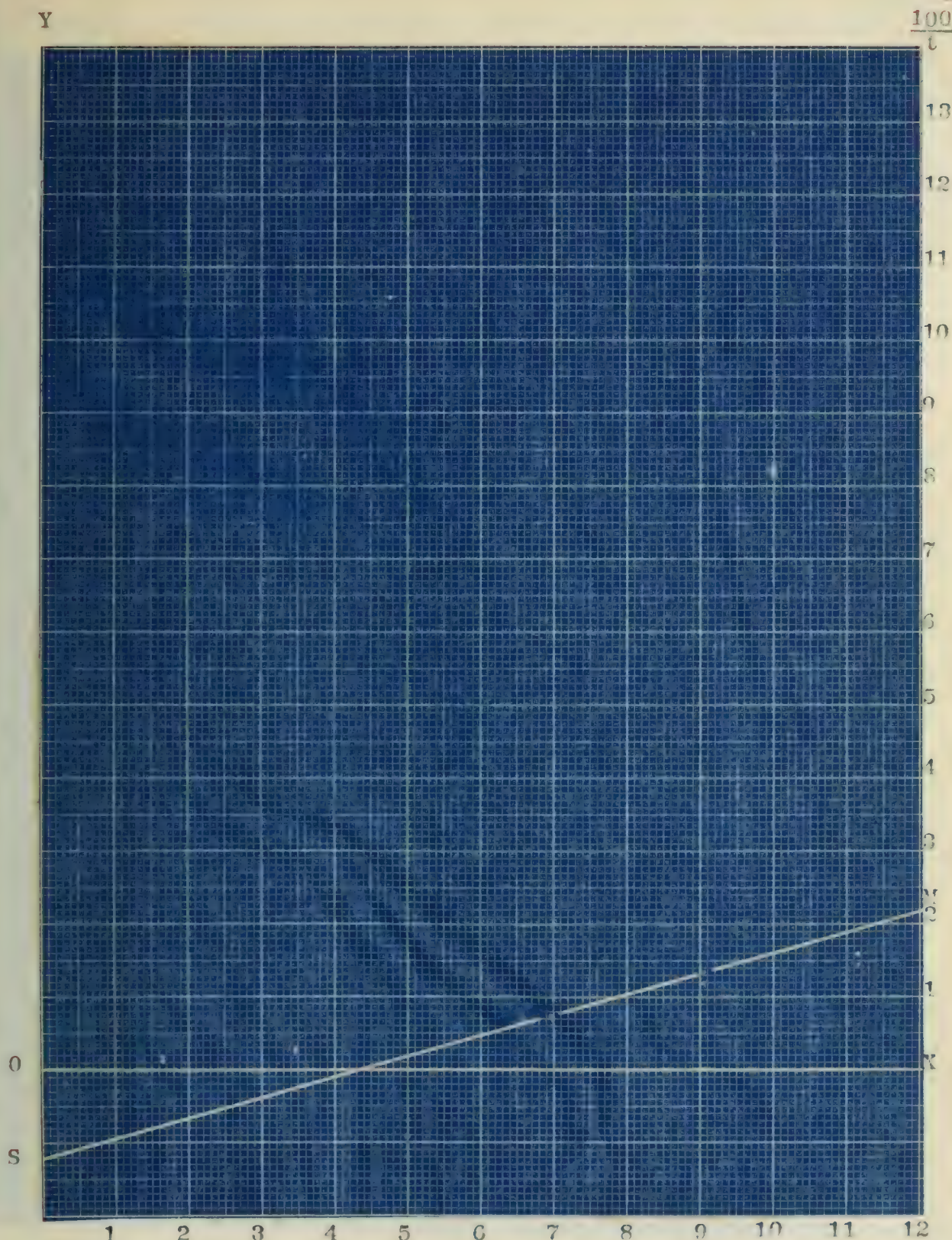


Figure 5. Graph showing the theoretical velocity of fatality curve of the goldfish when killed in lithium chloride solution at 11.8° C. Ordinate represents velocity of fatality and abscissa represents concentration of the lithium chloride. One block abscissa = 0.0333 N. lithium chloride. The circles (•) represent velocity of fatality of individual fish.

$$\frac{100}{t}$$

Y

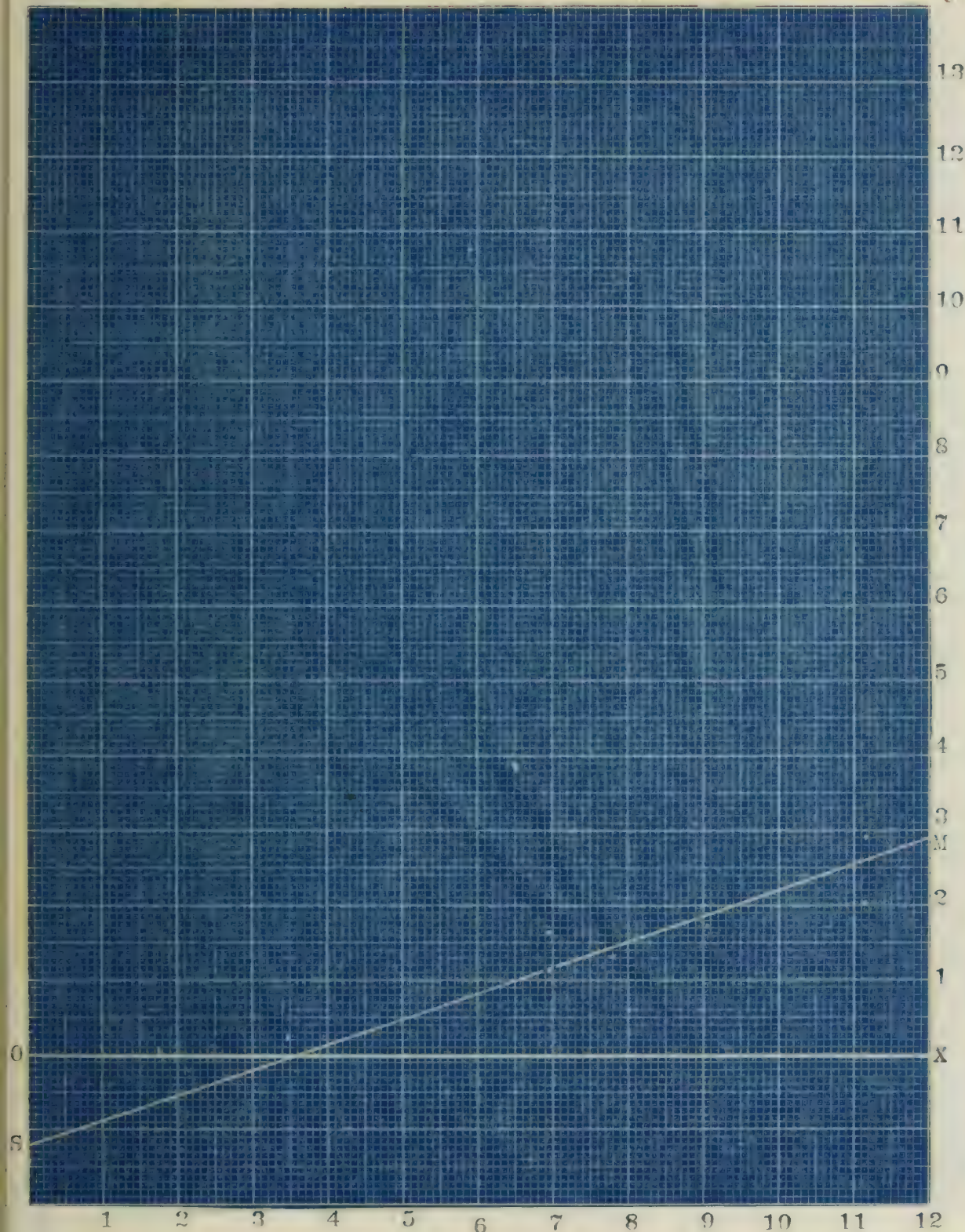


Figure 6. Graph showing the theoretical velocity of fatality curve of the goldfish when killed in lithium chloride solution at 15.3° C. Ordinate represents velocity of fatality and abscissa represents concentration of lithium chloride solution. One block abscissa = 0.0333 N. lithium chloride. The circles (•) represent velocity of fatality of individual fish.

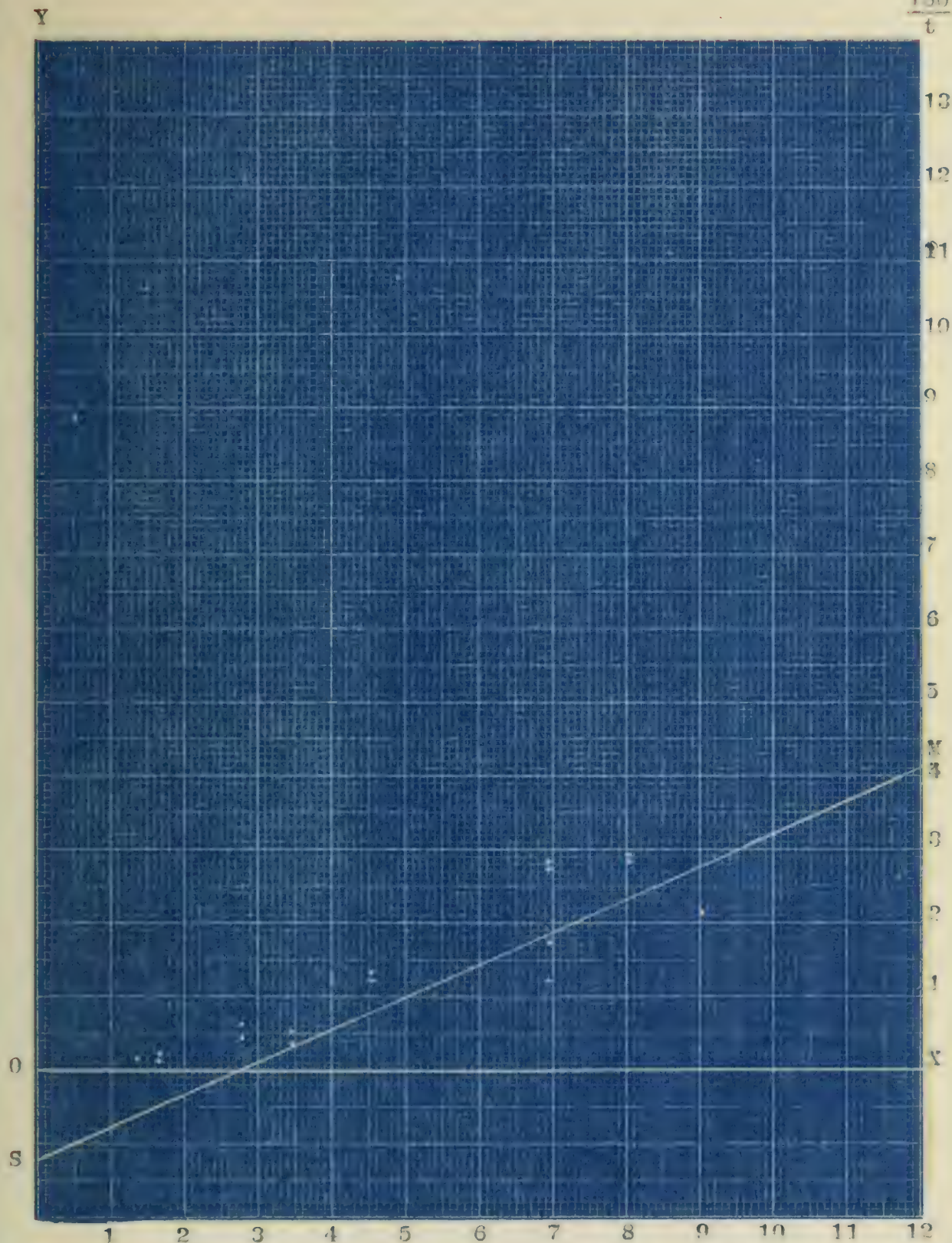


Figure 7. Graph showing the theoretical velocity of fatality curve of the goldfish when killed in lithium chloride solution at 20° C. Ordinate represents velocity of fatality and abscissa represents concentration of the lithium chloride solution. One block abscissa = 0.0333 N. lithium chloride. The Circles (•) represent velocity of fatality of individual fish.

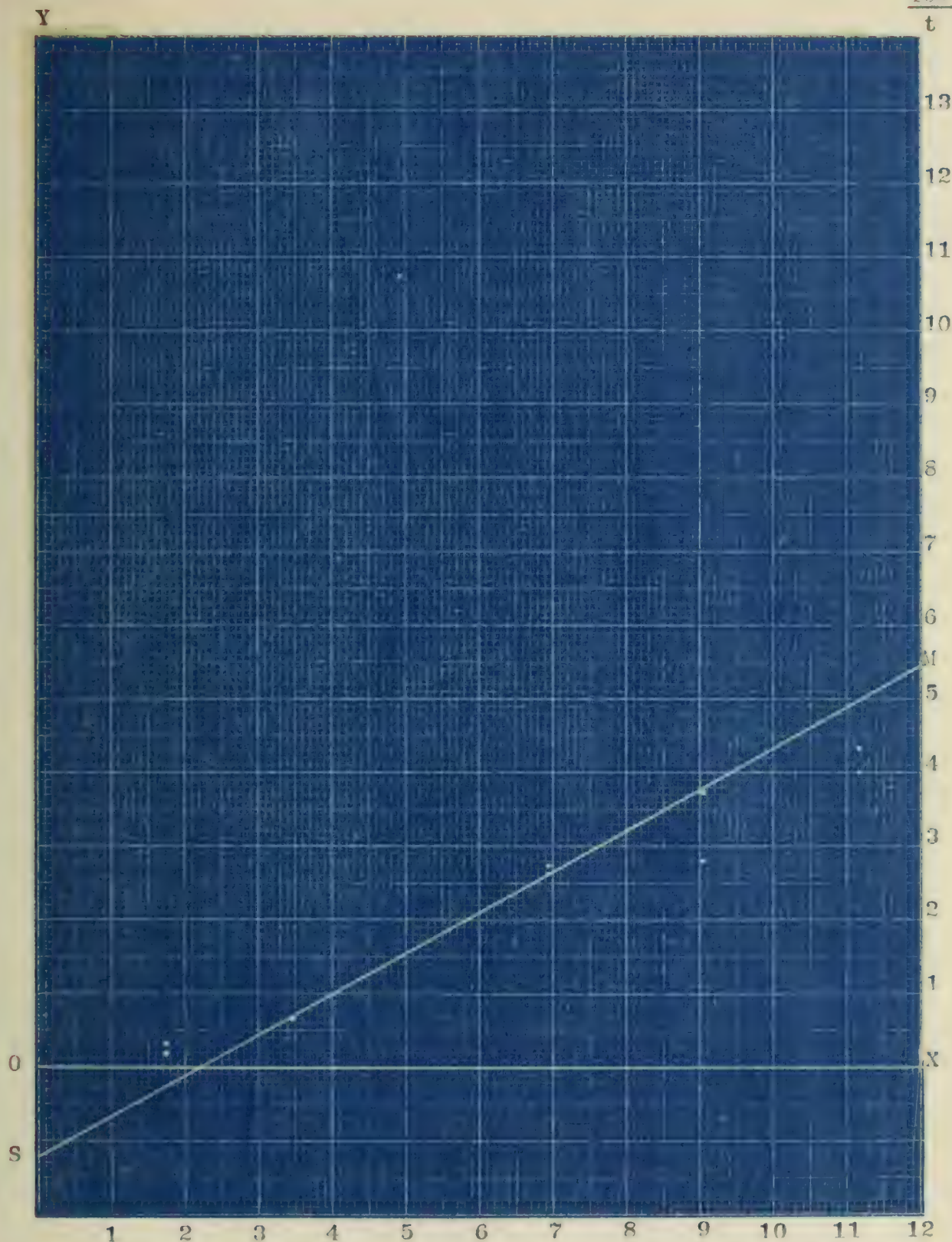


Figure 8. Graph showing the theoretical velocity of fatality curve of the goldfish when killed in a lithium chloride solution at 24.9° C. Ordinate represents velocity of fatality and abscissa represents concentration of the lithium chloride solution. One block abscissa = 0.3333 N. lithium chloride. The circles (•) represent velocity of fatality of individual fish.

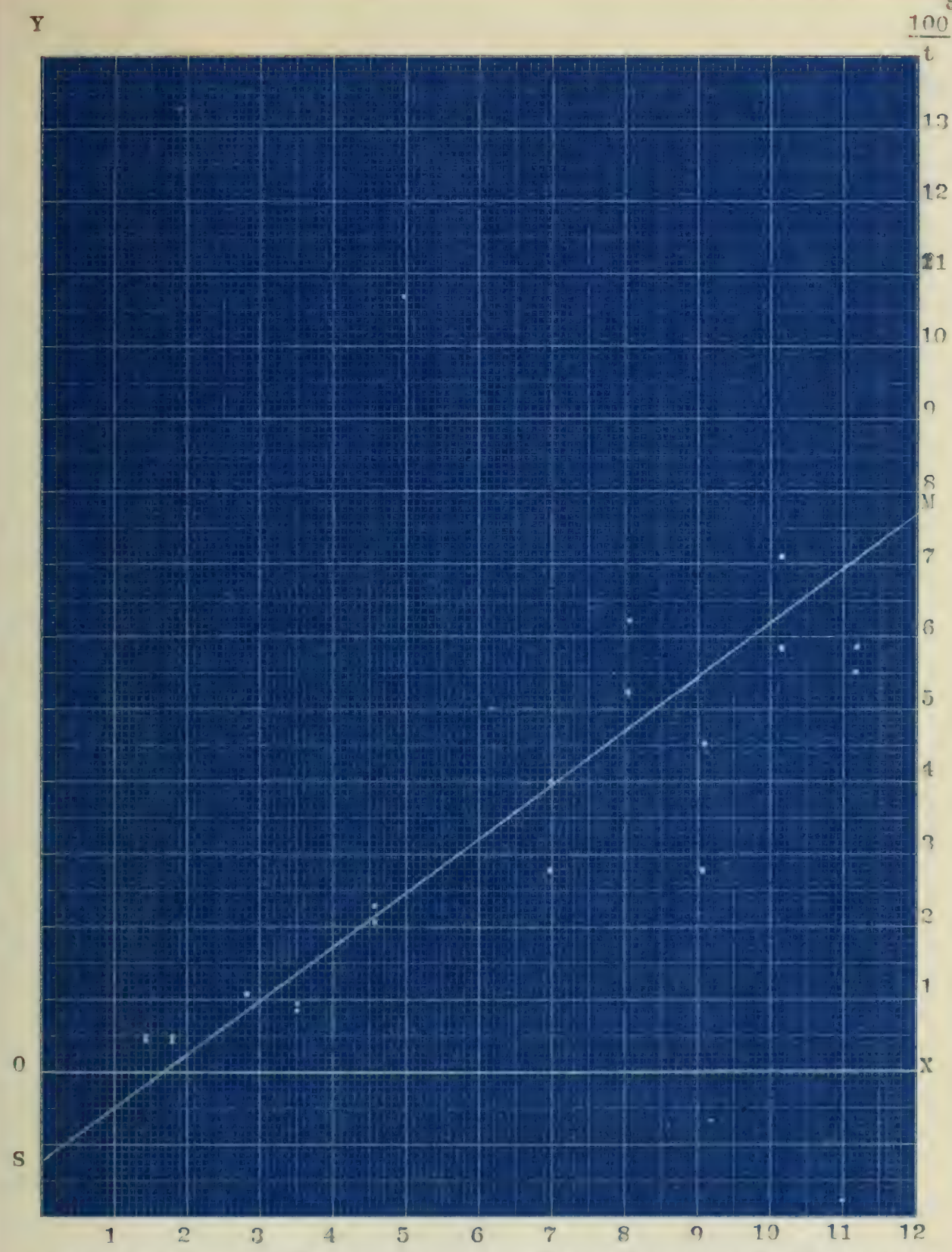


Figure 9. Graph showing the theoretical velocity of fatality curve of the goldfish when killed in lithium chloride solution at 29.8° C. Ordinate represents velocity of fatality and abscissa represents concentration of lithium chloride solution. One block abscissa = 0.0333 N. lithium chloride. The circles (•) represent velocity of fatality of individual fish.

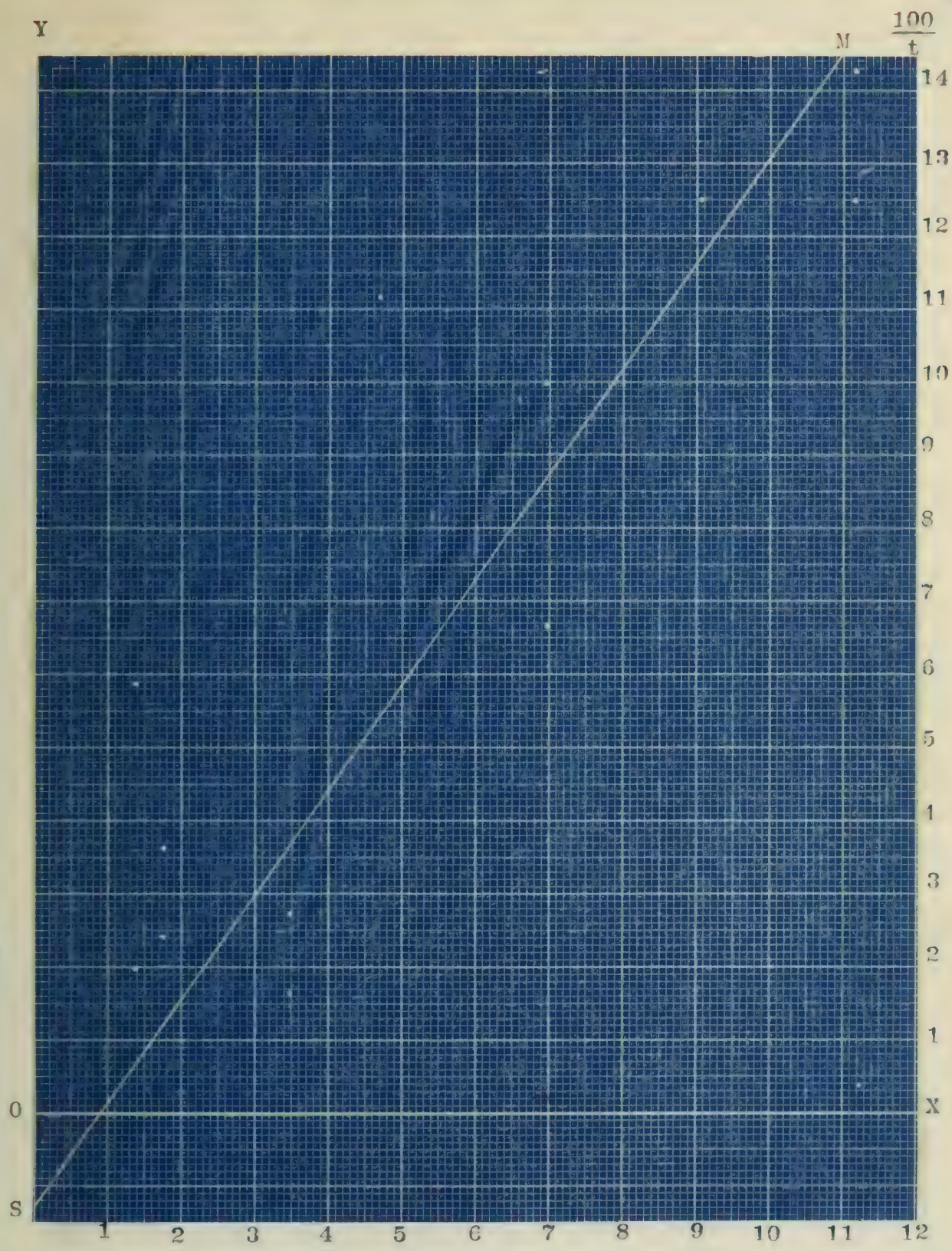


Figure 10. Graph showing the theoretical velocity of fatality curve of the goldfish when killed in lithium chloride solution at 34.8° C. Ordinate represents velocity of fatality and abscissa represents concentration of the lithium chloride solution. One block abscissa = 0.0333 N. lithium chloride. The circles (•) represent velocity of fatality of individual fish.

Y

34.8° C. 100

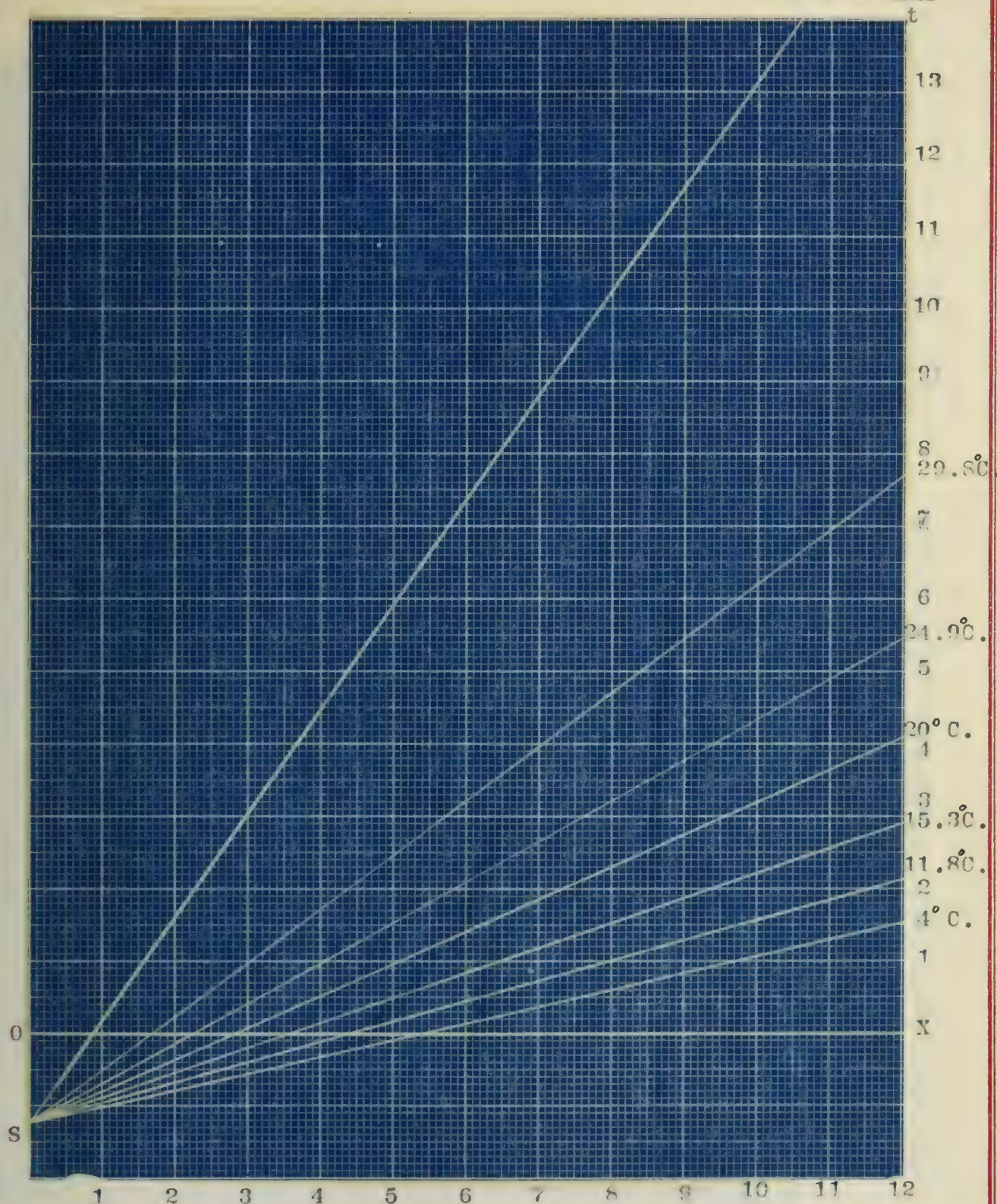


Figure 11. The theoretical velocity of fatality curves of the goldfish when killed at different temperatures in lithium chloride solution drawn for comparison. Ordinate represents velocity of fatality and abscissa represents concentration of the lithium chloride solution. One block abscissa = 0.0333 N. lithium chloride.

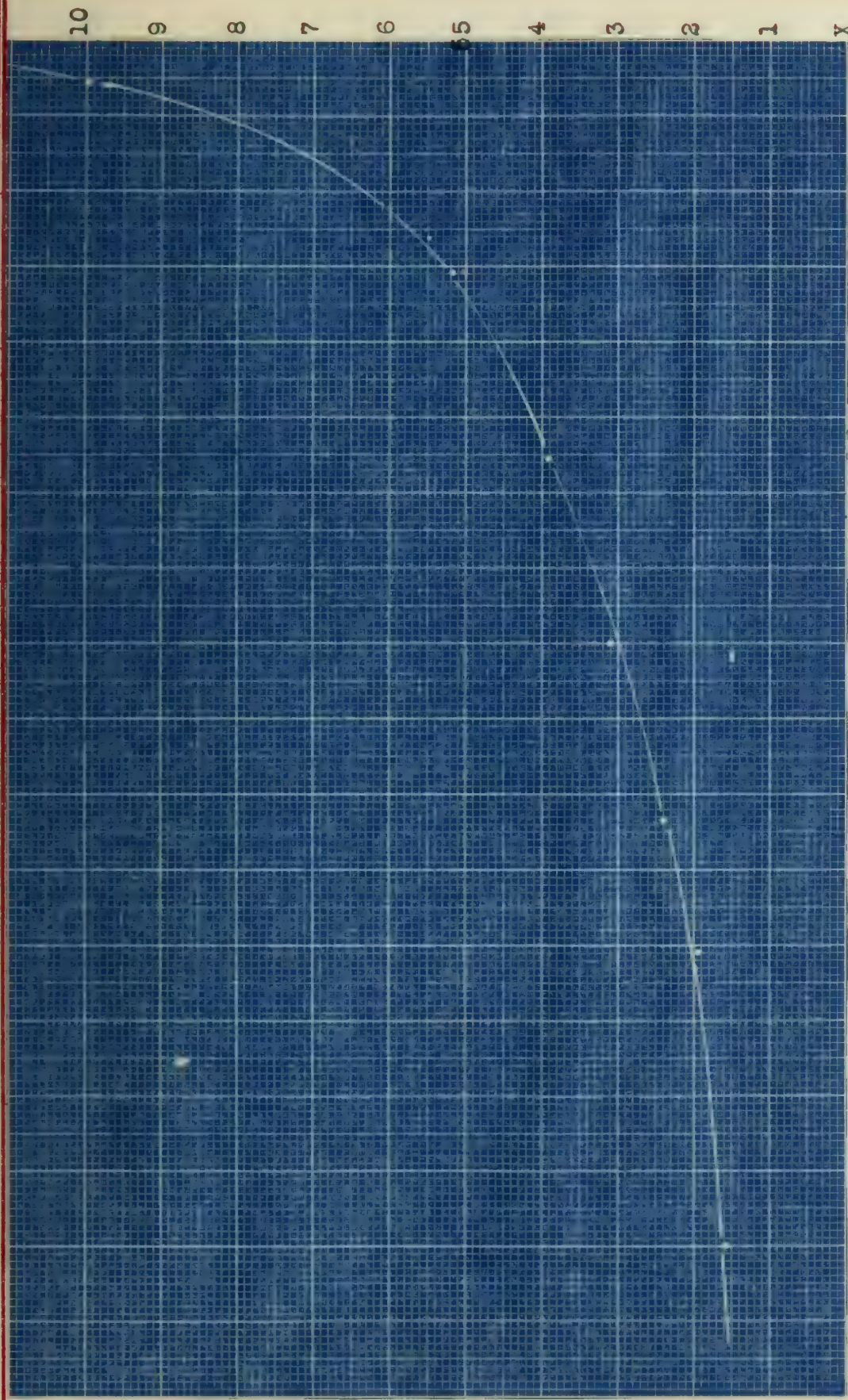


Figure 12. Graph showing temperature toxicity curve of lithium chloride to goldfish. Ordinate represents relative toxicity of the lithium chloride solution to the goldfish and abscissa represents temperature.

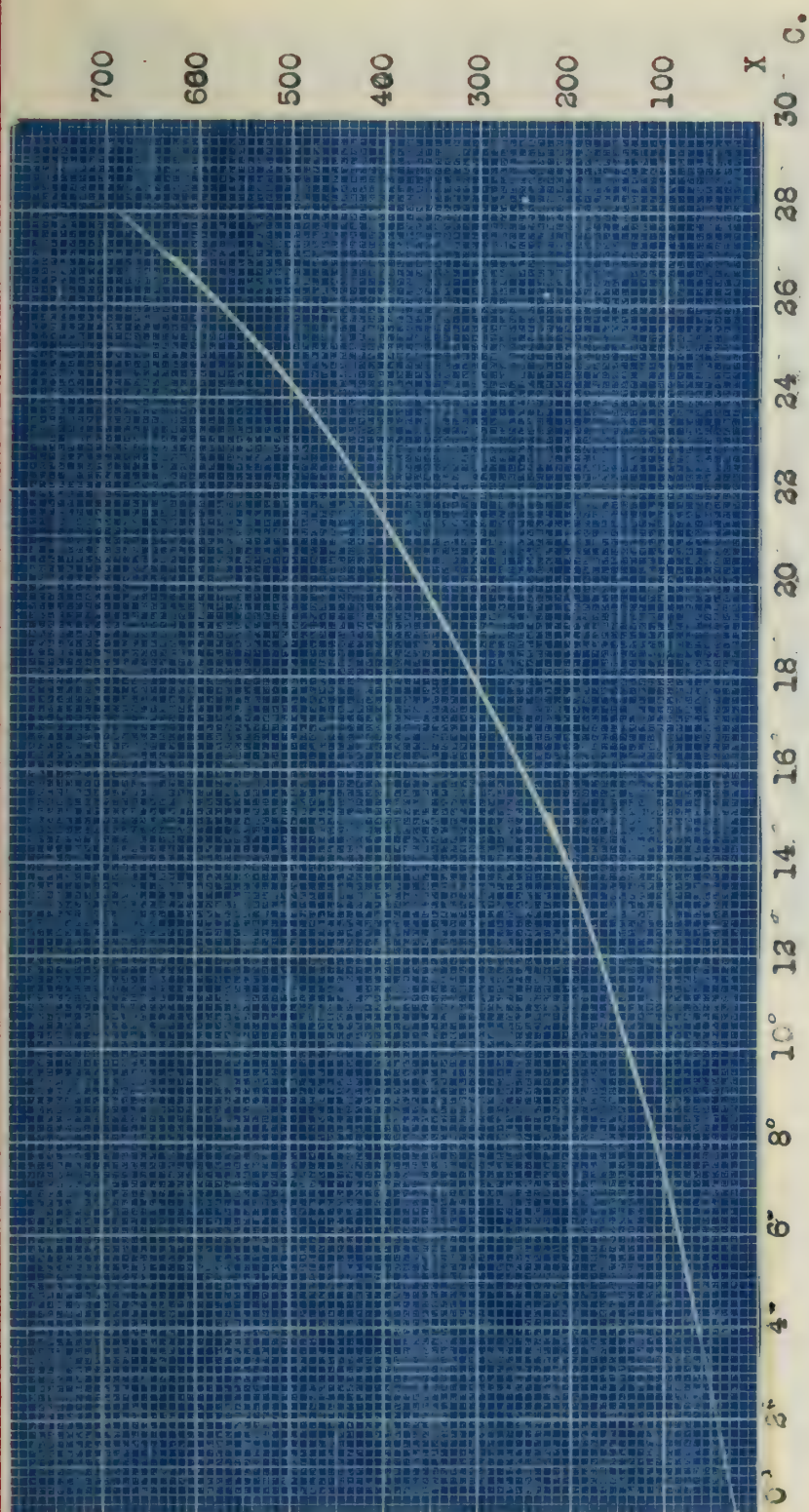


Figure 13. Temperature standard metabolism curve taken from Krogh (1914c). Ordinate represents relative rate of standard metabolism of vertebrates and abscissa represents temperature.



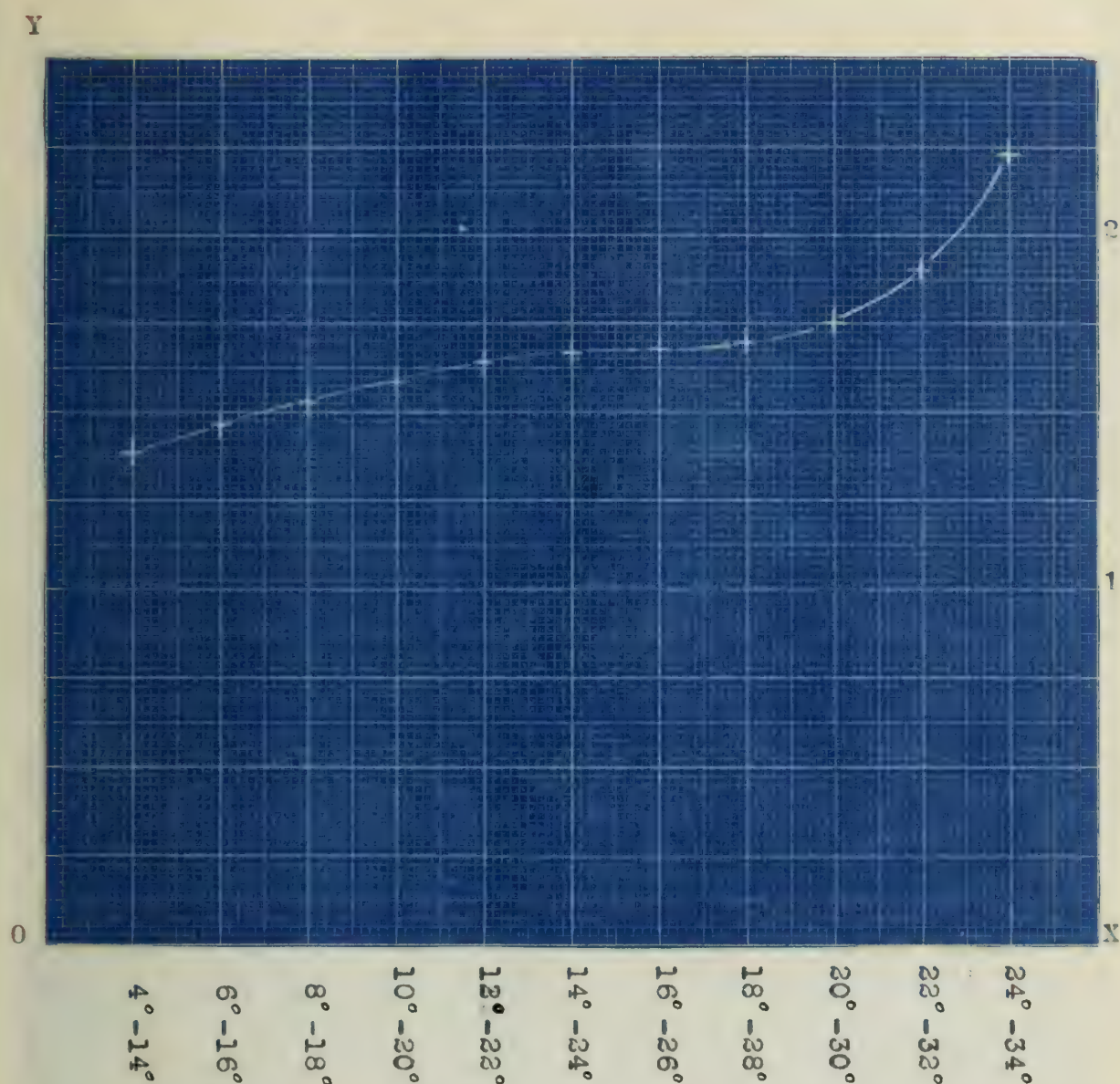


Figure 14. A graphic representation of the Q_{10} for the toxicity of lithium chloride to goldfish. Ordinate represents the Q_{10} and the abscissa represents the temperatures at which the Q_{10} is calculated.

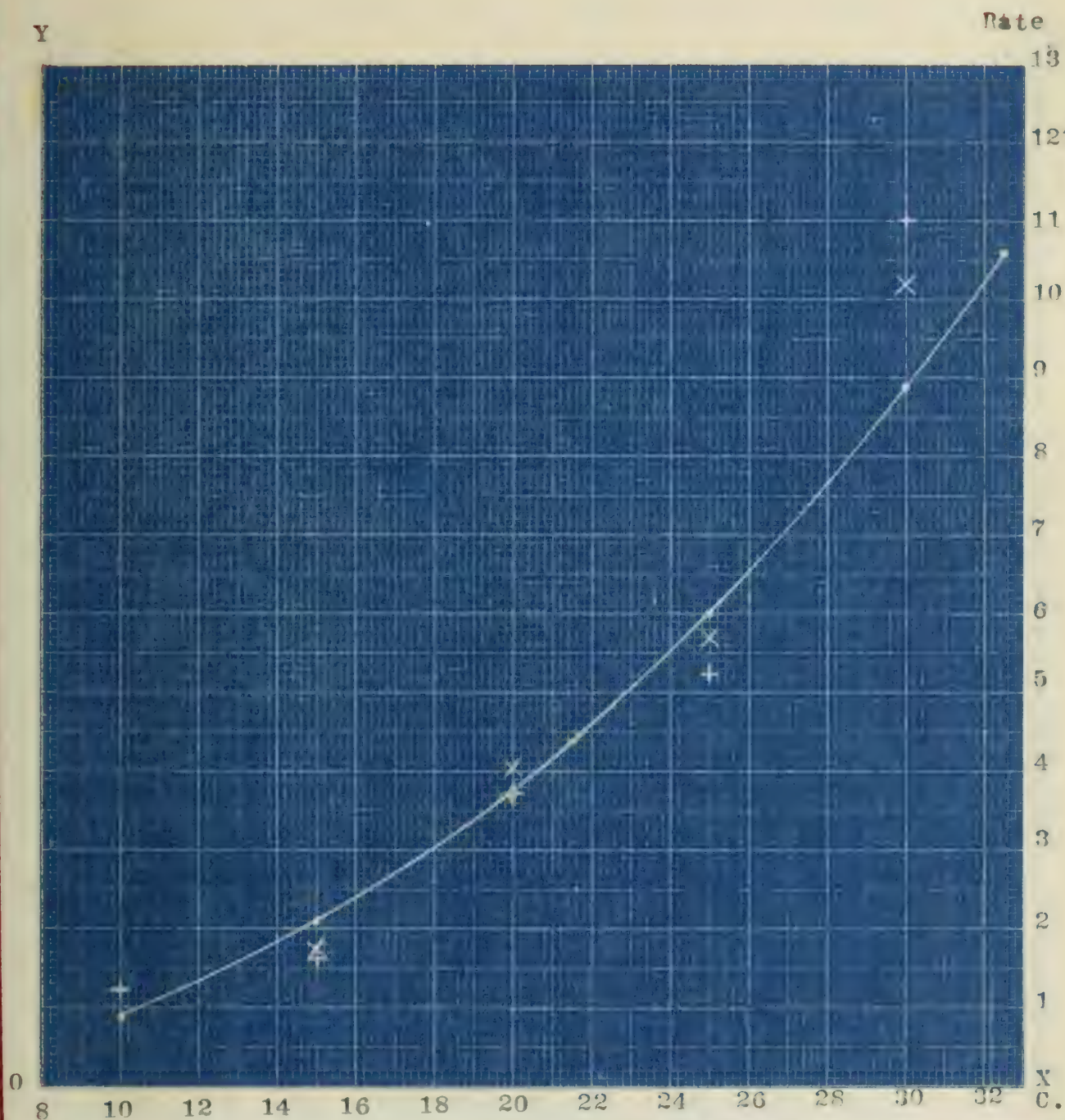


Figure 15. Graph showing temperature metabolism curve of Tenebrio molitor chrysalids (data given by Krogh 1914c) with relative duration of life of the imago and the relative total duration of life of Drosophila (data given by Loeb and Northrop 1917). Ordinate represents relative rate of metabolism of the Tenebrio chrysalids and the relative reciprocals of the duration of life of the imago and the total duration of life of Drosophila. Abscissa represents temperature. The circles represent data of the Tenebrio chrysalids. The Plus sign (+) represents the reciprocal of the duration of life of the imago and the crosses (X) that of the total life of Drosophila.

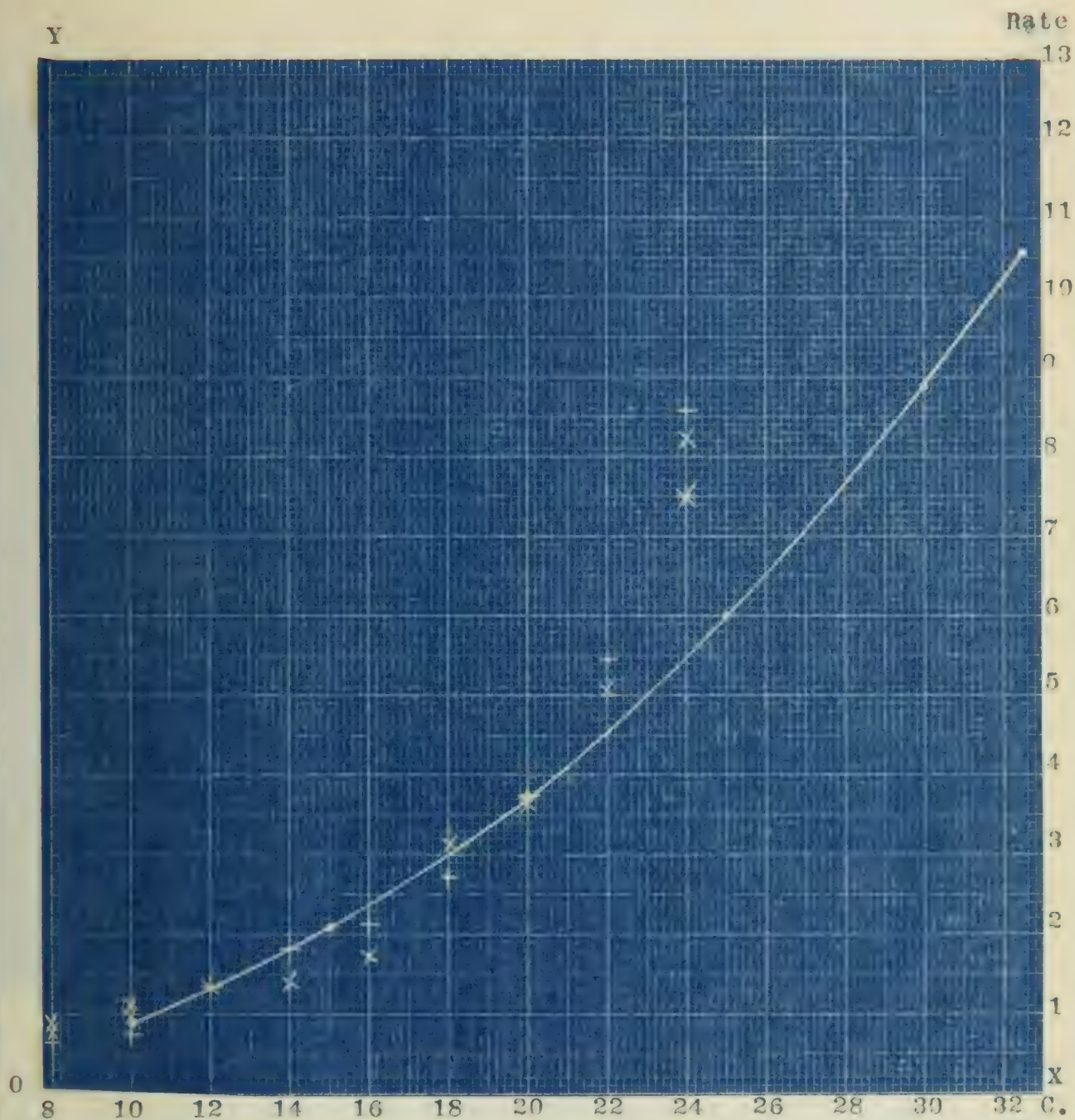


Figure 16. Graph showing temperature metabolism curve of Tenebrio molitor chrysalids (data given by Krogh 1914c) with relative rate of activation of starfish eggs (data given by Lillie 1917) superimposed. Ordinate represents relative rate and abscissa represents temperature. The circles (•) represent relative rate of metabolism of the Tenebrio chrysalids. The plus sign (+) represents relative rate of activation of Group B starfish eggs Table XVII and the crosses (X) represent the relative rate of Group A.

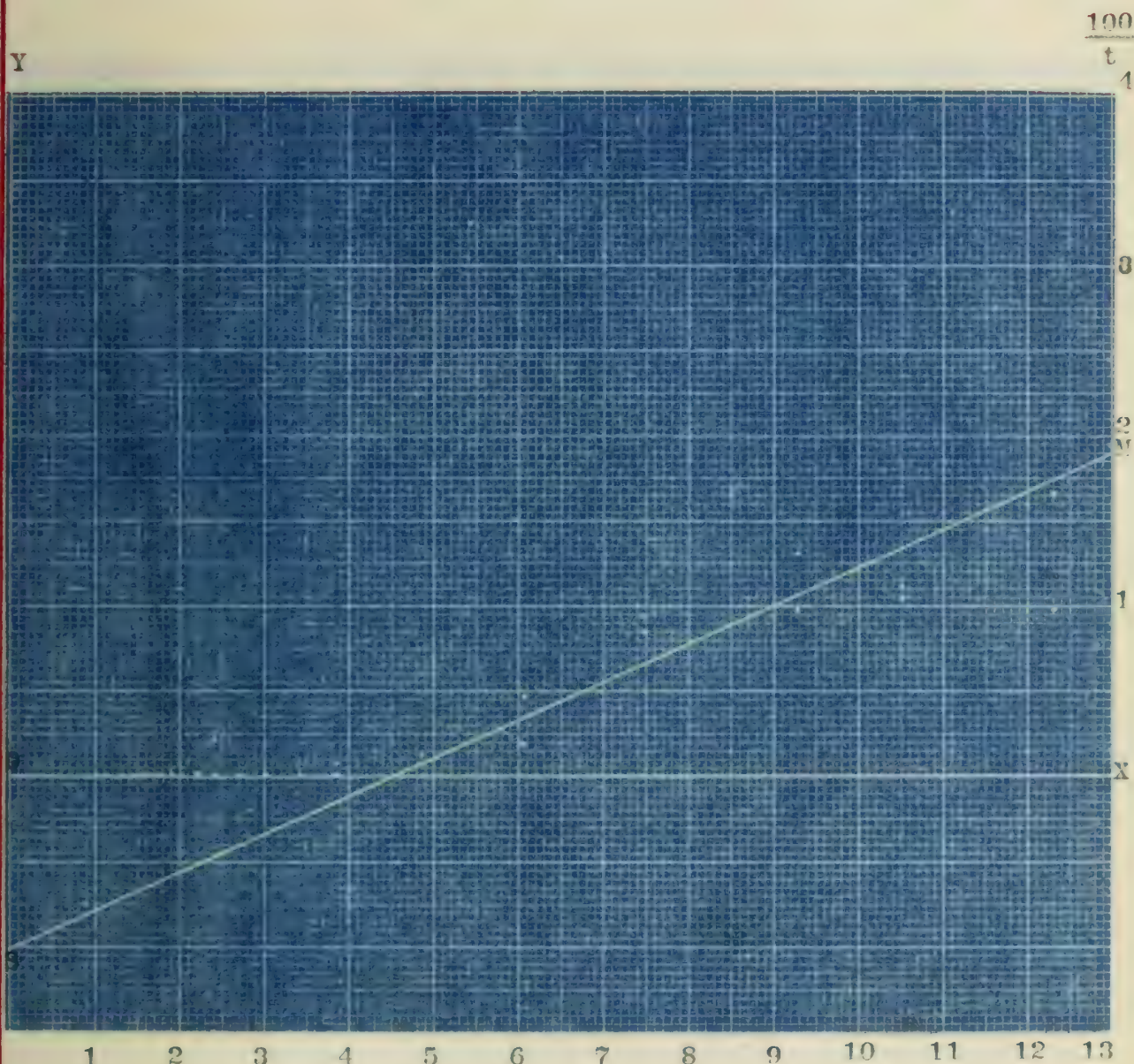


Figure 17. Graph showing the theoretical velocity of fatality curve of the blunt-nosed minnow when killed in ammonium chloride solution at 14.2°C . Ordinate represents velocity of fatality and abscissa represents concentration of the ammonium chloride solution. One block abscissa = 0.005 N. ammonium chloride. The circles (•) represent the velocity of fatality of individual fish.

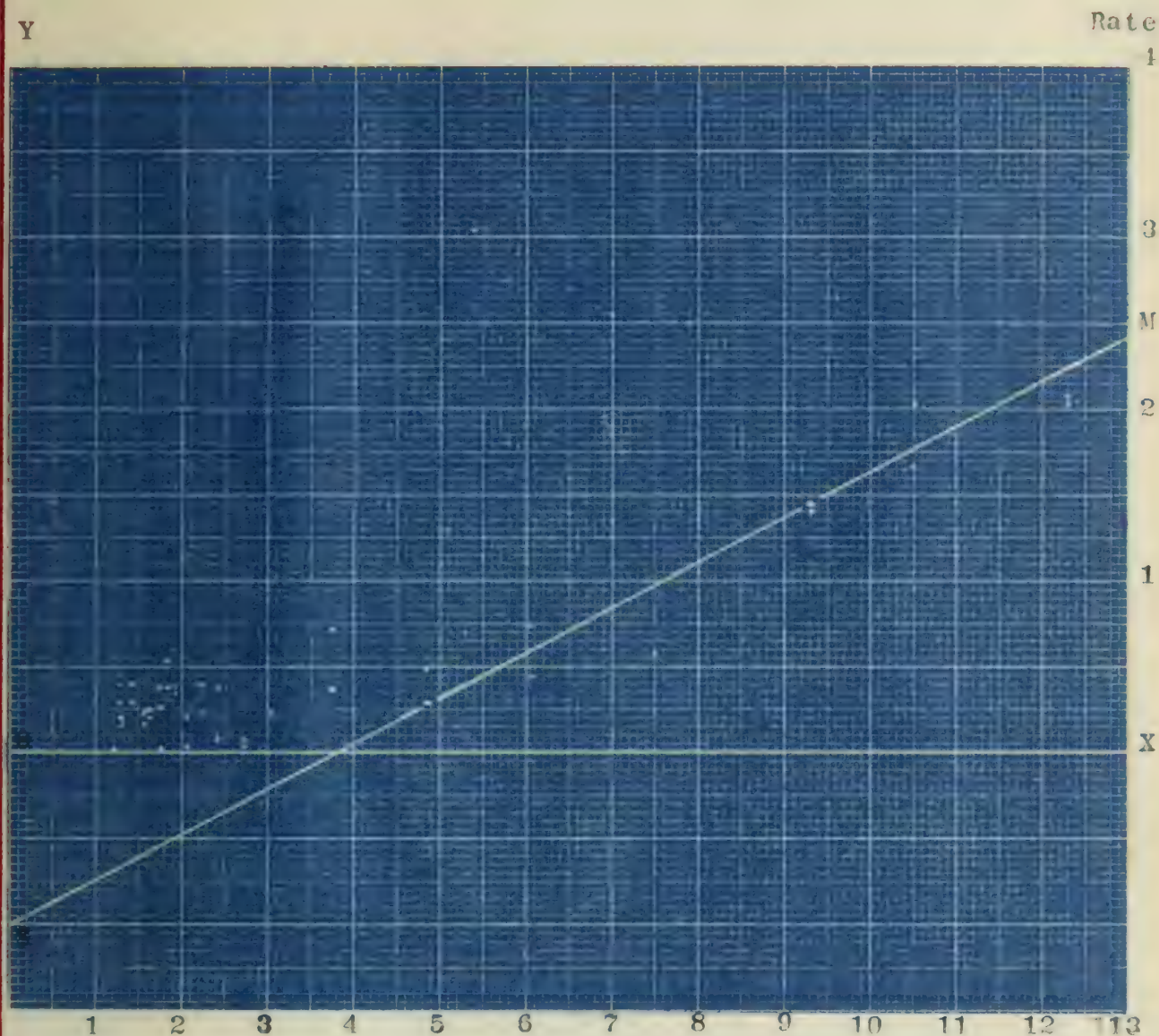


Figure 18. Graph showing the theoretical velocity of fatality curve of the blunt-nosed minnow when killed in ammonium chloride solution at 19.8°C . Ordinate represents velocity of fatality and abscissa represents the concentration of the ammonium chloride solution. One block abscissa = 0.005 N. ammonium chloride. The circles (•) represent velocity of fatality of individual fish.

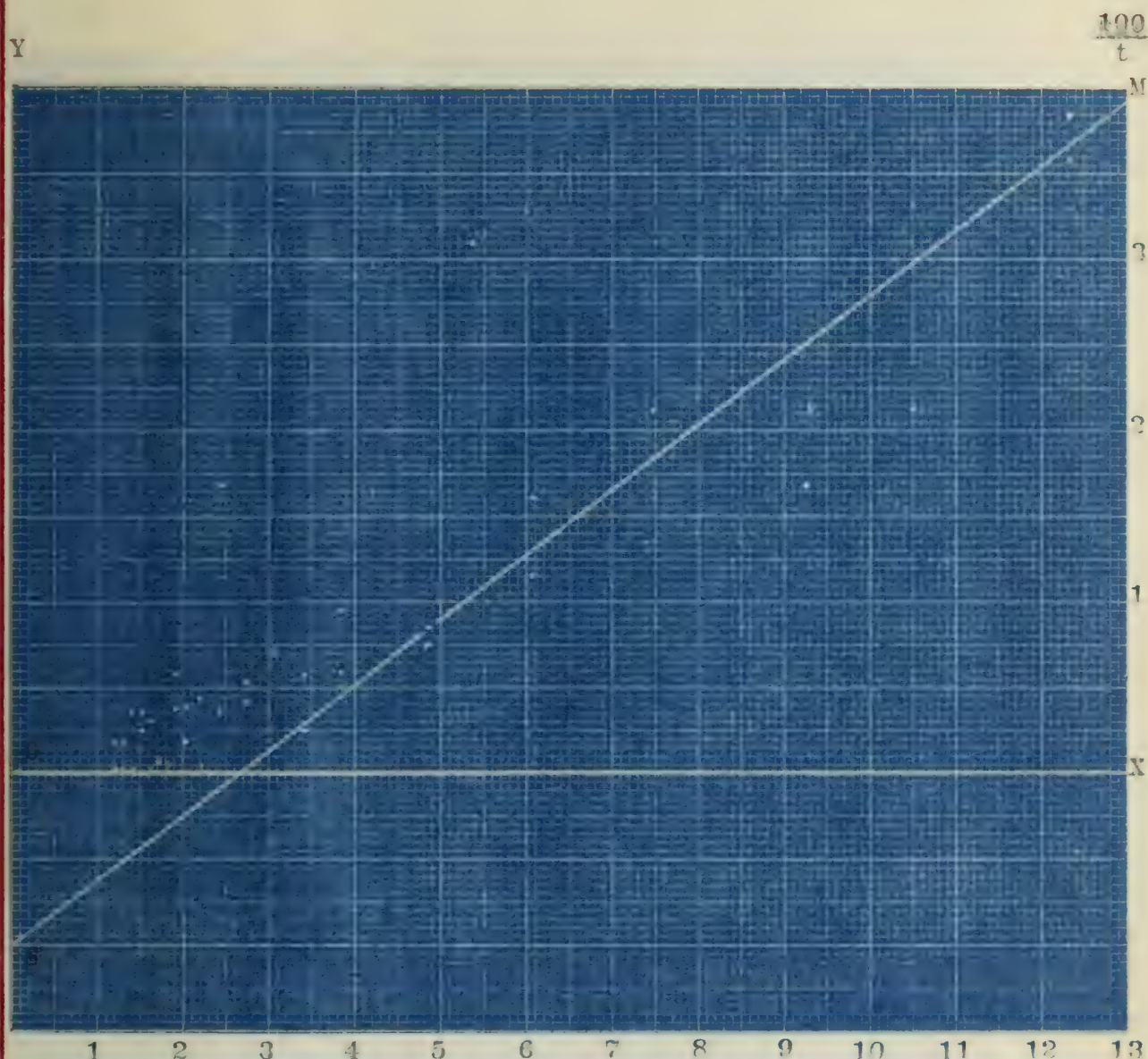


Figure 19. Graph showing the theoretical velocity of fatality curve of the blunt-nosed minnow when killed in ammonium chloride solution at 24.9°C. Ordinate represents velocity of fatality and abscissa represents the concentration of the ammonium chloride. One block abscissa = 0.005 N. ammonium chloride. The circles (•) represent the velocity of fatality of individual fish.

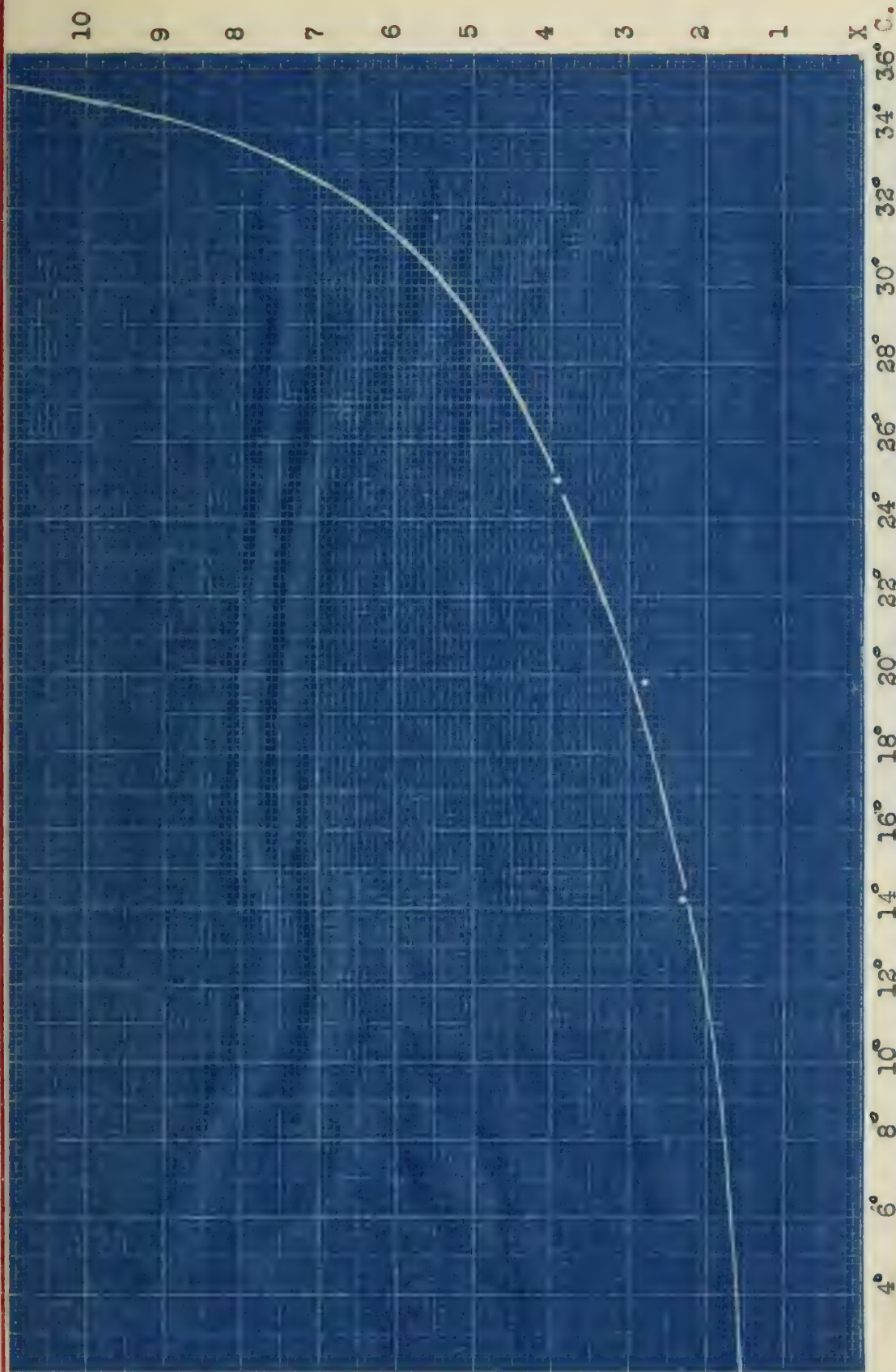


Figure 20. the temperature toxicity curve of lithium chloride to goldfish with the relative toxicity of ammonium chloride to the blunt-nosed minnow superimposed. Ordinate represents relative toxicity and abscissa represents temperature.

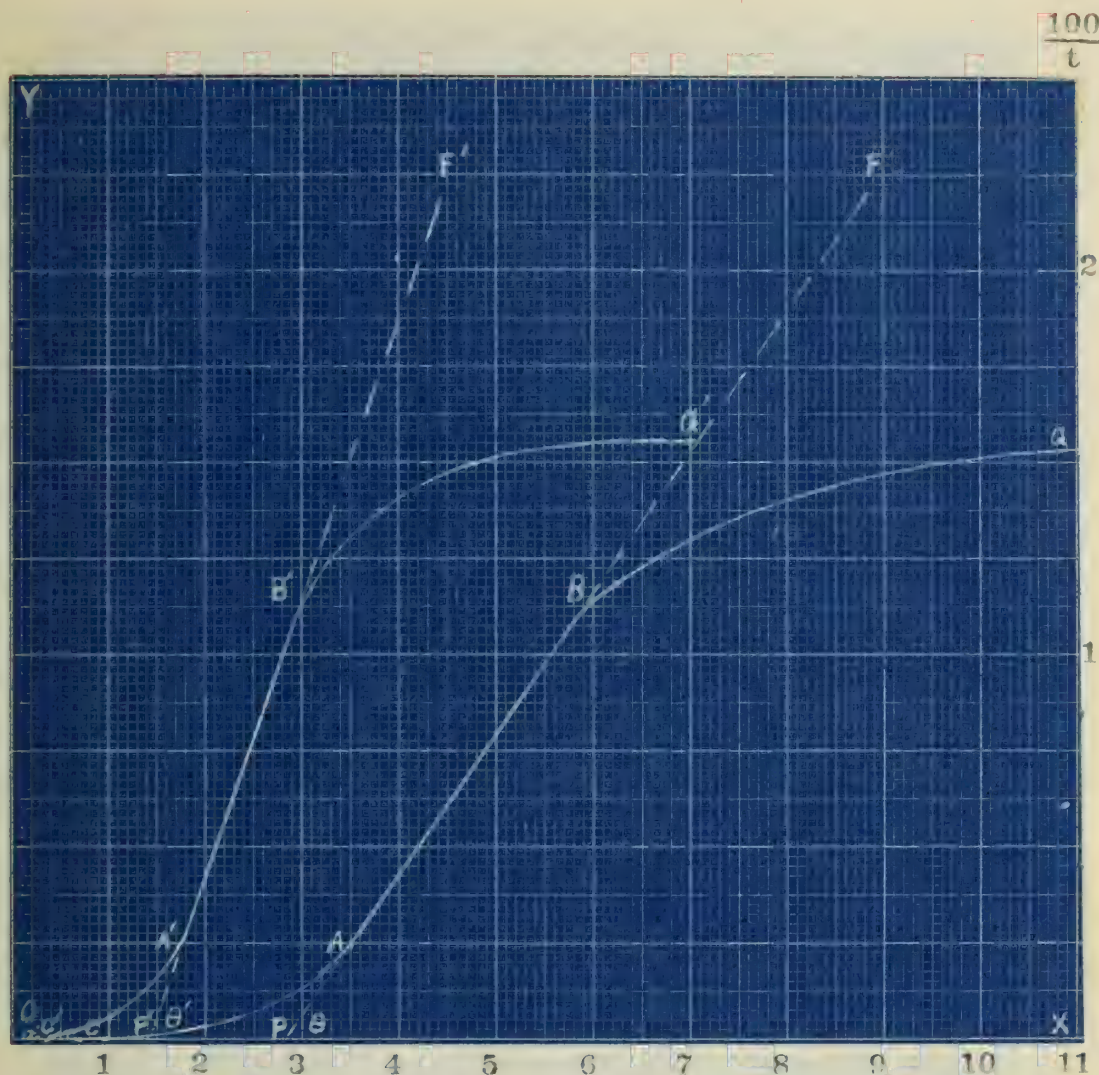


Figure 21: Graph shows the velocity of fatality curves CABG and C'A'B'G' and the theoretical velocity of fatality curves PABF and P'A'B'F' of two hypothetical solutions one having just one half the toxic activity of the other. The two curves are graphic representations of the data of experiments in which the blunt-nosed minnows were killed in different concentrations of ammonium chloride at 19.8° C. Ordinate represents velocity of fatality. In curve CABG one block abscissa = 0.008 N. ammonium chloride while in curve C'A'B'G' one block = 0.016 N. ammonium chloride.

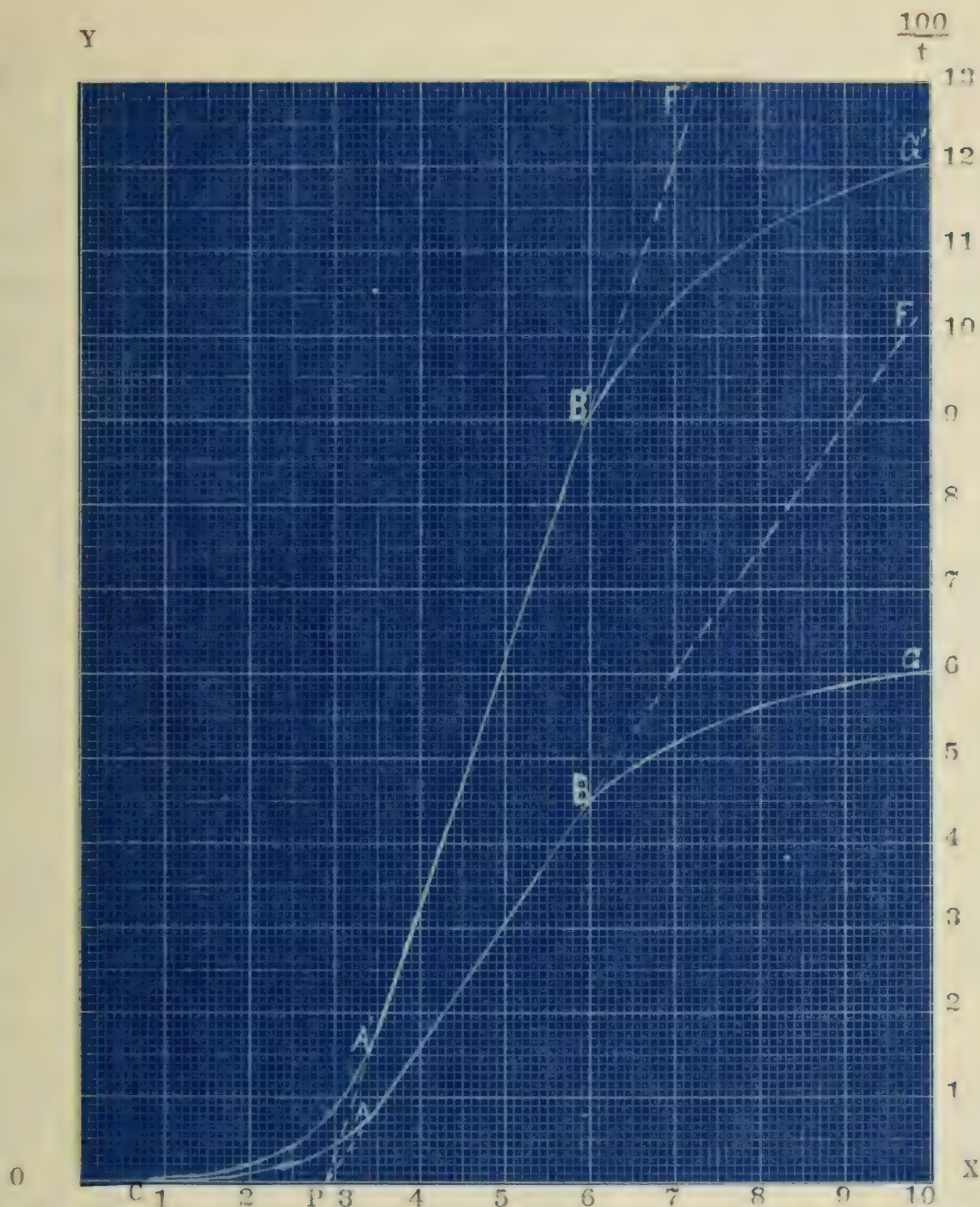


Figure 22. Graph shows the velocity of fatality curves CABC and CA'B'G' of two hypothetical solutions having the same threshold of toxicity concentration for fish but the velocity of fatality of the fish in one being just twice as rapid as in the other. The two curves are graphic representations of the data of experiments in which the blunt-nosed minnows were killed in different concentrations of ammonium chloride at 19.8° C. In both curves one block abscissa = 0.008 N. ammonium chloride. Four blocks ordinate = one unit of velocity of fatality in curve CABC. In curve CA'B'G' eight blocks ordinate = one unit of velocity of fatality of the fish.

VITA

Edwin Booth Powers was born at Ovilla, Texas, 1880. His preparatory work was done in the Ovilla School. In 1902 he entered Trinity University, Waxhachie, Texas, completing his college course and taking the A.B. degree in 1906. He spent the summer of 1905 at the University of Chicago as an undergraduate. The second and third year of his undergraduate course he was Assistant in Chemistry and the fourth year Assistant in Biology. During the year 1906-1907 he was teacher of science in the Terrell High School, Terrell, Texas. In the year 1907-1908 he was Principal of the Ovilla School at Ovilla, Texas. He was Instructor of Biology at Trinity University 1908-1910 and Professor of Biology 1910-1915 with leave for 1912-1913. The summers of 1908, 1910, 1913, and 1915, the last term of the summer of 1914, and the year 1912-1913 were spent at the University of Chicago as graduate student and he took his A.M. degree at that institution in June of 1913. During the most of his stay at the University of Chicago he held a scholarship and was Assistant in Zoology during the summer of 1913 and 1915. During the summer of 1915 he was Research Assistant in Zoology at the Puget Sound Biological Station. He spent the years 1915-1918 as graduate student in the University of Illinois. The first year he was Assistant in Zoology and the second year he was a Fellow in Pharmaceutical Research. During the summer of 1917 he was Entomological Assistant in the Illinois State Natural History Survey. During the academic year 1915-1916 he was elected to Sigman Xi. During the period of his graduate study he published the following papers:-

The Reactions of Crayfishes to Gradients of Dissolved Carbon Dioxide and Acetic and Hydrochloric Acids. Biol. Bull., 27: 177-200, 1914.

An Experimental Study of the Movements of Herring and Other Marine Fishes. Biol. Bull., 28:315-334, 1915. (By Victor E. Shelford and Edwin B. Powers.)

A Collecting Bottle especially adapted for the Quantitative and Qualitative Determination of Dissolved Gases, particularly very small Quantities of Oxygen. Bull. Ill. State Lab. Nat. Hist., Vol. 11, Article 10, 1918.

The Goldfish (*Carassius carassius* L.) as a test Animal in the Study of Toxicity. Ill. Biol. Mon., Vol. 4, No. 2, 1918.

The question of the existence of a
single state and the possibility of
1917-18, 1918.
An experimental study of the movement of
other states. 1917-18, 1918. (By
T. J. and R. J. R. R. R.)
A collection of papers especially selected for the
active and qualitative determination of the
very small quantities of oxygen. 1917-18, 1918.
Vol. 11, Article 10, 1918.
The question of the existence of a
single state and the possibility of
1917-18, 1918. Vol. 11, Article 10, 1918.
1918.

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